TRANSACTIONS

OF

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THE ANNUAL ADDRESS OF THE PRESIDENT

THE ORIGIN AND DEVELOPMENT OF THE PROJECTION MICROSCOPE[1]

By SIMON HENRY GAGE

WITH SIX PLATES AND NINETEEN FIGURES IN THE TEXT.

INTRODUCTION

No more timely subject, it seems to me, can be discussed in a presidential address before the American Microscopical Society than the origin and development of the projection microscope[2], since by the universality of the electric light many can make use of this most potent means of illustration.

When the task was begun it was not thought that the trail would lead so far back into the past nor be so obscure and difficult to follow. In following up the trail it becomes increasingly evident that the records of human achievement are secondary records only;

[1]The main part of this address was given with demonstrations at the meeting of the Society in June, 1906, but the final revision was finished only in January, 1908. It is hoped that during the present year the work may be carried to completion, adding to the figures in this address, illustrations of the best modern apparatus with full directions for installation, and methods of use; and the numerous applications in teaching and in investigation.

[2]Some of the names by which the projection microscope is known; it will be seen that the name is frequently derived from the source of light:

the real individuals who discovered the principles and made the original, fundamental inventions were often lost sight of, while the mere recorder or encyclopedist is credited with the inventions and discoveries which his writings popularized. It is hoped that by the full notes and references given the reader will gain some adequate notion of the steps of progress, and that, where there is no certain knowledge, he will also perceive the uncertainty.

The author wishes to acknowledge his indebtedness to Andrew D. White's Warfare of Science with Theology in Christendom. This work gives a broad view of the history of science and with its numerous references puts one in the way of following an historical search in any field of science no matter how special, like this on the projection microscope. Without this book and the numerous old Latin folios and other works in the White Historical Library of Cornell University, it would have been impossible to trace so far and so fully the development of the subject of this address.

In nature one can trace more and more, with increasing knowledge, each result to some antecedent; so in human attainment, when time has given the necessary perspective, every stage seems not only logical, but as necessary and unavoidable as the steps in a mathematical demonstration.

It might have been predicted that the genius of man would in the fullness of time learn to compensate for the congelation of the once elastic lens of the eye and the consequent ineffectiveness of the muscle of accommodation. In this age of artificial helps for defective eyesight, one can but faintly conceive of the cloud that in earlier times slowly settled upon the aging human being as the

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Camera obscura microscope, Ger., Camera-obscura Mikroskop; electric microscope, Ger., Photoelectrische Mikroskop, Ital., microscopio fotoelettrico; lucernal, lamp or lantern microscope, Lat., lucerna megalographica, Ger., Lampenmikroskop; laterna magica, or magic lantern; oxy-hydrogen, hydro-oxygen or gas microscope, Fr., microscope au gaz, Ger., Gasmikroskop, Hÿdrooxygenmikroskop, Ital., microscopio a gaz; picture microscope, Ger., Bildmikroskop; projection microscope, Lat., microscopium per projectionem, Fr., microscope de projection, Ger., Projectionsmikroskop; solar microscope, Lat., microscopium solare, Fr., microscope solaire, Ger., Sonnenmikroskop, Ital., microscopio solare.

crystalline lens gradually lost its elasticity, and near objects could no longer be clearly seen. Cooper makes one feel this keenly in his descriptions of the young hero in the Deerslayer, named by the Indians Hawkeye, and of the same hero in The Prairie with the weight of years upon him. One voice has come down to us from the time when this cloud was first brushed aside. It dates from the year 1299, and comes from Florence in Italy: "I find myself so pressed by age that I can neither read nor write without those glasses called spectacles, lately invented to the advantage of poor old men when their eye-sight grows weak." (Carpenter-Dallinger, p. 124.)[1]

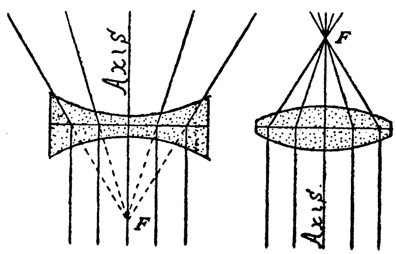

Fig. 1 **Fig. 2**

Figs. 1, 2. Concave, thick-edged, or divergent, and convex, thin-edged, or convergent lenses. Spectacles for "poor old men when their eyesight grows weak" are almost always of convex lenses, while shortsighted eyes are fitted with spectacles with concave lenses.

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[1]CARPENTER-DALLINGER, p. 124: "The name of microscope, like that of telescope, originated with the Academy of the Lincei, and it was Giovanni Faber who invented it, as shown by a letter of his to Cesi, written April 13, 1625, and which is amongst the Lincei letters in the possession of D. B. Boncompagni. Here is the passage in Faber's letter: 'I only wish to say this more to your Excellency, that is, that you will glance only at what I have written concerning the new inventions of Signor Galileo; if I have not put in everything, or if anything ought to be left unsaid, do as best you think. As I also mention his new *occhiale* to look at small things and call it microscope, let your Excellency see if you would like to add

It may be asked, what have spectacles to do with projection microscopes? Everything, for from the invention and knowledge of spectacle lenses grew directly the possibility of the invention of all kinds of optical instruments, including the microscope in all its forms. The spectacle lenses for "poor old men when their eyesight grows weak" means here and generally convex lenses, that is those which will form real images, and on the possibility of forming real images by lenses rests the whole development of the telescope, the compound microscope, and the projection microscope.[1]

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that, as the Lyceum gave to the first the name of telescope, so they have wished to give a convenient name to this also, and rightly so because they are the first in Rome who had one'." POGGENDORFF, *Gesichte der Physik*, p. 197, says: "Ein Mitglied der Accademia dei Lyncei, ein geborener Grieche Demiscianus, gab den Fernröhren and Vergrösserungsgläsern ihre jetzt gebräuchlichen Namen Teleskop und Mikroskop, welche bis dahin Conspicilia, Perspicilia, Occhiali, Occhialini genannt wurden." Poggendorff does not give the date when the Greek, Demiscianus, gave the name telescope and microscope, so it is difficult to reconcile Carpenter-Dallinger's statements and his.

[1]PORTA, *Natural Magick*: The 17th Book; Of *Burning-glasses, and the wonderful sights by them. Chap. XXI, p. 379. How spectacles are made*: "We see that Spectacles were very necessary for the operations already spoken of, or else lenticular Crystals, and without these no wonders can be done. It remains now to teach you how Spectacles and Looking-glasses are made, that every man may provide them for his use. In Germany there are made Glass-balls, whose diameter is a foot long, or there abouts. The Ball is marked with the Emril-stone round, and is so cut into many small circles, and they are brought to Venice. Here with a handle of Wood are they glewed on by Colophonia melted; and if you will make Convex Spectacles, you must have a hollow iron dish, that is a portion of a great Sphaere, as you will have your Spectacles more or less Convex; and the dish must be perfectly polished. But if we seek for Concave Spectacles; let there be an Iron-ball, like to those we shoot with Gun-powder from the great Brass Canon: the superficies whereof is two, or three foot about: Upon the Dish, or Ball there is strewed white-sand, that comes from Vincentia, commonly called Saldame, and with water it is forcibly rubbed between our hands, and that so long until the superficies of that circle shall receive the Form of the Dish, namely, a Convex superficies, or else a Concave superficies upon the superficies of the Ball, that it may fit the superficies of it exactly. When that is done, heat the handle at a soft fire, and take off the Spectacle from it, and joyn the other side of it

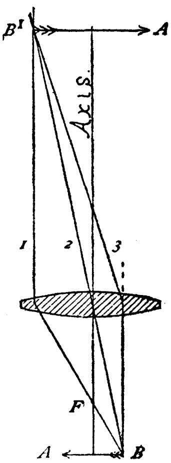

Fig. 3

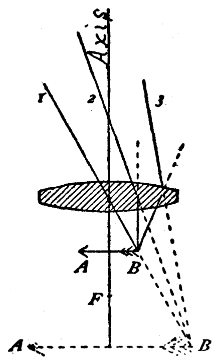

Fig. 4

Fig. 3. A convex lens showing that when used for producing real images the object is beyond (below in the figure) the principal focus, and the real image is formed on the opposite side of the lens and is inverted. The objectives of a compound microscope, and of a projection microscope act like this simple lens.

Fig. 4. A convex lens used as a simple microscope or magnifier. In this case the object is within the principal focus (above in the picture), and the image appears to the observer to be on the same side of the lens as the object and not inverted.

From the first production of lenses every kind of experiment was tried to see what could be done with them. In this period of about four centuries from the introduction of lenses to the invention of the compound microscope there was a very close alliance between

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to the same handle with Colophonia, and work as you did before, that on both sides it may receive a Concave or Convex superficies; then rubbing it over again with the powder of Tripolis, that it may be exactly polished; when it is perfectly polished, you shall make it perspicuous thus. They fasten a woolen-cloth upon the wood; and upon this they sprinkle water of Deparr, and powder of Tripolis; and by rubbing it diligently, you shall see it take a perfect Glass. Thus are your great Lenticulars, and Spectacles made at Venice."

science and magic, or rather science had not yet emerged from magic. The effort was great to produce striking effects and by secret devices to make them appear supernatural. In the multitude of trials some one, perhaps several quite independently, found that a convex lens placed in a small opening of the shutter of a darkened room gave a much more brilliant and distinct image of the outside world than did a chance hole in the shutter when no lens was used.

A darkened room or cabinet with a white wall or screen, a convex lens in the wall or shutter, and a brilliantly lighted object or landscape outside form a camera obscura or magic lantern *(laterna magica)*. A projection microscope is simply a magic lantern in which the lens or system of lenses in the wall or shutter is of relatively short focus and the image on the screen is much larger than the object.

The magic lantern and its various uses were described by many writers between 1500 and 1700. L. da Vinci, who died in 1519, spoke of a Benedictine monk, dom. Panunce, who used a camera obscura. Porta in his book, *Magiæ naturalis,* 1553, described the camera obscura[1], and was so successful in its employment that he

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[1]PORTA, *Natural Magick:* The 17th book; *Of Burning glasses and the wonderful sights by them.* Pp. 364-5. *How in a Chamber you may see Hunting, Battles of Enemies, and other delusions*: "Now for a conclusion I will add that, then which nothing can be more pleasant for great men, and Scholars, and ingenious persons to behold; That in a dark Chamber by white sheets objected, one may see as clearly and perspicuously, as if they were before his eyes, Huntings, Banquets, Armies of Enemies, Plays, and all things else that one desireth. Let there be over against that Chamber, where you desire to represent these things, some spacious Plain, where the Sun can freely shine: Upon that you shall set Trees in Order, also Woods, Mountains, Rivers, and Animals, that are really so, or made by Art, of Wood, or some other matter. You must frame little children in them, as we use to bring them in when Comedies are Acted; and you must counterfeit Stags, Bores, Rhinocerets, Elephants, Lions, and what other creatures you please; Then by degrees they must appear, as coming out of their dens, upon the plain: The Hunter, he must come with his hunting Pole, Nets, Arrows, and other necessaries, that may represent hunting: Let there be Horns, Cornets, Trumpets sounded; those that are in the Chamber shall see Trees, Animals, Hunters, Faces, and all the rest so

got the reputation of being a wizard, a reputation not quite so safe and complimentary then as now. Cellini in the middle of the 16th century described the phantasmagoric images he saw projected upon smoke in the Colosseum at Rome. In the second edition of his work, *Ars magna lucis et umbræ,* Kircher discusses at considerable length the magic lantern; some of his figures are reproduced in this address. Dechales says in the *Mundus mathematicus,* that in 1665 a learned Dane showed him a magic lantern (text-fig. 6). Zahn in the *Oculus artificialis,* 1685-6, figures and describes several forms of magic lantern. From the above it is seen that a knowledge of the magic lantern was widely diffused during the 16th and 17th centuries. *No one knows who the first inventor was.* Probably several individuals devised it in various degrees of perfection. It has been the custom to ascribe its invention to Bacon, to Porta,

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plainly, that they cannot tell whether they be true or delusions: Swords drawn will glister in at the hole, that they will make people almost afraid. I have often showed this kind of Spectacle to my friends, who much admired it, and took pleasure to see such a deceit; and I could hardly by natural reasons, and reasons from the Opticks remove them from their opinion, when I had discovered the secret. Hence, it may appear to Philosophers, and those that study Opticks, how vision is made; and the question of intromission is taken away, that was anciently so discussed; nor can there be any better way to demonstrate both, than this. The Image is let in by the pupil, as by the hole of a window; and that part of the Sphere, that is set in the middle of the eye, stands instead of a Crystal Table. I know ingenious people will be much delighted in this. It is declared more at large in our Opticks. From hence may one take his principles of declaring anything to one that is confederate with him, that is secret, though the party be far off, shut up in prison. And no small Arts may be found out. You shall amend the distance by the magnitude of the Glass. You have sufficient. Others that undertook to teach this, have uttered nothing but toyes, and I think none before knew it."

In this paragraph Porta describes the camera obscura, and while he does not here explicitly state that the hole into the darkened room has a lens in it, one can feel sure that a lens was there, for he compares his camera with the eye, the pupil corresponding with the hole in the darkened room. the sphere set in the middle is the crystalline lens of the eye. Then in the paragraph on the preparation of spectacles (lenses) he says "without these glasses no wonders, like those already spoken of, can be done." Such a camera obscura involves all the fundamental principles of projection whether with a single lens in the shutter or the most complex microscopical outfit.

to Dechales, to Kircher and to other writers whose works have come down to us. It would be just as correct to ascribe the invention of the telegraph, the discovery of radium and the many other wonderful things of our period to popular writers in magazines or to editors of encyclopedias.

In nearly all the old writings in which the magic lantern is dealt with, the subject is discussed and references are made to their predecessors and to other books as if what they were discussing had been known for a long time. If one reads Porta's preface (see the Bibliography) one could hardly ascribe to him the invention or discovery of the wonderful things described in his book and he nowhere claims such distinction. So in the works of Kircher, Dechales, Zahn, and others one is constantly reminded of modern encyclopedias, that is of collections and expositions of what is already known or imagined.

The Projection Microscope

To deal now more specifically with the particular form of magic lantern known as a projection microscope, it is, as stated above, simply a magic lantern with a short-focus objective serving to show small objects greatly enlarged. To comprehend the purpose of a projection microscope it must be remembered that the microscope, whether a simple magnifier or the most elaborate compound microscope, is an aid to the eye and becomes for the time being a part of the visual apparatus of the person using it. But the social and teaching instincts could not be satisfied without being able in some way to share the pleasure derived from the exquisite forms revealed by the microscope. Hence there was an effort to do away with the virtual or individual image seen on looking into a microscope, and to produce real images on a white screen where all in the room could see at the same time, and in which the leader could point out parts as in a large picture while the members of the audience could ask questions and discuss points, being sure that every one knew what was under discussion.

In some cases drawings or colored paintings were made on metal mirrors and properly arranged before a lens in the shutter of a darkened room. The mirror being set at the proper angle reflected

the light through the lens into the room and upon the screen where the drawing on the mirror appeared more or less perfectly (text-fig. 5; pl. I). Sometimes a thin coat of honey was spread over

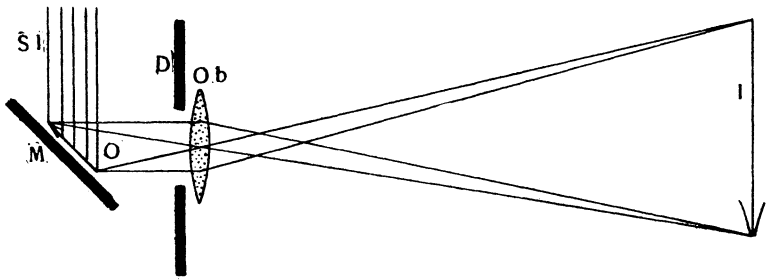

Fig. 5. Diagram showing the method of producing magic lantern pictures by painting the object to be exhibited directly on the mirror. Compare plate I from Kircher. *Sl*, rays of the sun; *M*, mirror; *O*, object (an arrow) on the mirror; *D*, hole in the shutter of a darkened room; *Ob*, objective; *I*, image (inverted on the screen).

the mirror and then living insects placed upon it. The honey prevented the too rapid locomotion of the insects and increased their efforts.[1] If one repeats this experiment at the present time

[1]KIRCHER, p. 794. Caput VII. *De scenica, seu historica repraesentatione rerum*: "Si vero muscas vivas exhibere desideres; limbus speculi melle illiniatur, & ecce muscarum per superficiem speculi quaqua versus gradientium umbrae in murum projectae vivas ibidem, sed insignis magnitudinis muscas repraesentabunt. Hoc idem artificium per magentem exhiberi poterit; nam muscae, vel aliae quaevis res acu instructae ductum magnetis ex posteriori parte speculo applicati, quocumque artifex voluerit sequentur. Certe hae repraesentationes adeo arcanae sunt, ut nisi modus expresse spectantes doceretur, vix quispiam Magicae artis suspicionem evadere posset." In this place Kircher describes the use of honey on the mirror to show living insects. He also speaks of the use of a magnet behind the mirror and the necessity of an explanation to the spectators to avoid the suspicion of magic. The text with the figures from Kircher (Pls. I, II and III) will give a good idea of his general treatment of the subject.

he will have no difficulty in appreciating the effect such exhibitions must have had in lessening the tedium of those old days.[1]

Dechales says concerning the magic lantern of the learned Dane (1665) that it is a veritable microscope, and for many purposes far better than an ordinary microscope. Zahn also, in the *Oculus artificialis,* describes the use of the magic lantern for showing small objects and says it is a kind of miscroscope. While Kircher did not specifically call the magic lantern a microscope, he used it for the purpose of showing small insects on the screen.

As early then as 1665 the *laterna magica* was used for microscopic projection and it was recognized as a kind of microscope.

Sometime before 1736 Fahrenheit of thermometer fame produced a projection microscope which was seen by many people in Amsterdam. Among these were Lieberkühn the anatomist. Naturally it appealed greatly to him as a means of demonstrating the fine structures he was so skillful in preparing. He had a projection microscope made and took it with him on his visit to England (1737-8). In England it created great interest, and as this was the first knowledge the English opticians and scientific men had of the projection microscope they very naturally attributed its invention to Lieberkühn. This error has persisted up to the present day in English and French works on the microscope (see Mayall, p. 41; Chevalier, p. 65), although as shown above, Deschales and Zahn had used and recognized the magic lantern as a microscope over 70 years before.[2] In justice to Lieberkühn it should be said that nowhere in his writings does he claim to be the inventor.

In the middle of the 18th century the projection microscope with its essential features was a well known and much used instrument

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[1]In my own work with the projection microscope and in the preparation of this address, I have repeated all the principal experiments of the older workers, with, to use the expression of a previous generation, "much edification and no little enjoyment."

[2]DECHALES, *Mundus Mathematicus,* T. III, Dioptricae, Liber I, p. 680. Propositio LVII, Theorema. *Exigui prototypi, uniea lente convexa amplificatam imaginem, in pariete exhibere.* "Videmus hic Lugduni dioptricam machinam, sub nomine laternae magicae, è qua radii luminis, per tubum uno circiter pede longum erumpentes, in pariete 10 aut 12 pedes distante

both in England and on the Continent, not only for popular exhibitions but for scientific purposes.

The crude forms figured by Dechales, Kircher and Zahn contained all the essential elements: A radiant to illuminate the object, a convex lens or a combination of lenses to project the image; and a darkened room or a cabinet with a whitened surface or screen to receive the projected image.

All the efforts since the fundamental invention of the camera obscura have been directed toward improving the method of lighting and perfecting the projecting lenses and the mechanical means for facilitating the working of the instrument.

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exigui prototypi imaginem suis coloribus illustrem, & mirum in modum amplificatam exprimebant." Dechales shows in this proposition that one can produce the same and even better projection with a single than with two convex lenses (see fig. 6) and concludes that these two lenses of the magic lantern in fig. 6 act like a single lens.

Ibid. Liber II, p. 696, Propositio XX, Problema. *De nocte exigui prototypi ingentem in muro imaginem distinctam exhibire duabus lentibus.* "Jam superiori libro (p. 680) indicavi eruditum Danum, hoc anno 1665 Lugduno transiisse, qui in dioptrica benè versatus inter alia laternam [magicam] exhibuit, è qua erumpebat tubus unius circiter pedis, ... Tubus duabus lentibus convexis instructus erat [fig. 6] . . . . . Primò quò murus in quo exprimenda erat imago magis distabit, eò etiam major erat imago . . . . Tertio imaguncula in laterna inversa erat, ut sui effigiem erectam in opposito pariete exhiberet, ablatâ imaguncula solus apparebat circulus integer lucidus." In the magic lantern of the learned Dane with two convex lenses (fig. 6), the large image of the object will be erect if the small object is inverted, and the more distant the wall or screen the larger will be the image. If the object is removed there will be a circle of light on the wall.

Ibid. Liber II, p. 698, Corollarium [to proposition XX]. "Microscopium habes in hujusmodi machina [fig. 6] quod tamen ad usum revocare poteris sine illa. Si enim tubo eadem vitra inseras nempè primum digitorum 5, secundum digitorum 10. primòque imponas muscam aut quodcúmque objectum minutum, tum illud ita soli obvertas, ut transmittatur solis radius in opposito pavimento; habebis illius objecti imaginem. Nam solis radius idem praestat quod lumen à speculo reflexum." In this corollary Dechales states emphatically that in this machine (fig. 6) one has a microscope which can be put to greater use than an ordinary microscope; further, that by turning the tube toward the sun the sunlight serves for illumination instead of light reflected from a mirror.

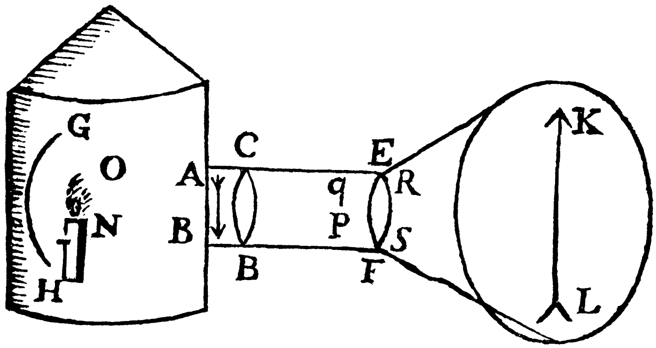

Fig. 6. Diagram from Dechales (p. 697), showing the laterna magica of the learned Dane (1665). It is described as a veritable microscope, the two lenses acting as a single lens to produce the enlarged image (p. 680). Toy magic lanterns precisely like this are on sale at the present time. *G-H,* concave speculum or mirror to concentrate the light of the lamp (*O-N*) on the object at (*A-B*); *C-B, E-F,* two convex lenses serving to form the image on the screen (*K-L*). The two lenses are movable and the closer the screen the farther apart are the lenses placed. The farther off the screen the larger the image and the closer are the lenses brought together. By discarding the lamp and turning the tube directly toward the sun good images are also produced (p. 698). (See fig. 7.)

Lighting

As shown by the quotation from Porta (1589) and by the figures copied from Dechales and Kircher (figs. 6-8), both sunlight and lamp light were used from the earliest times. As also seen, mirrors, concave and plane, were used to reflect the light upon the object or into the instrument.

Kircher and Deschales used convex mirrors for lamp light. Dechales also states that a good light may be obtained by omitting the lamp and directing the instrument toward the sun.

The apparatus taken to England by Lieberkühn was without a mirror and must be directed toward the sun (fig. 7). Cuff, a London optician, devised a method used to this day whereby the apparatus remained stationary and the light of the sun was reflected into the instrument by a movable plane mirror (fig. 8; pl. IV, A).

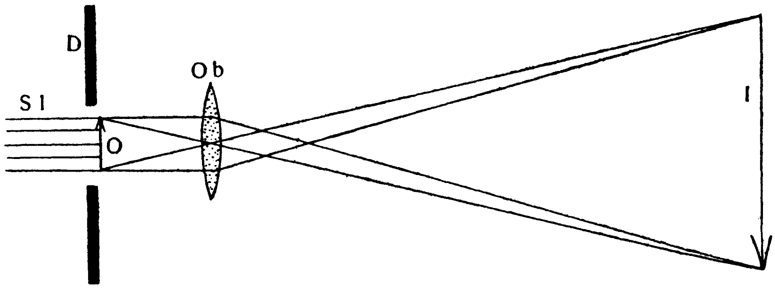

Fig. 7. Diagram of the projection microscope or magic lantern with the object illuminated by turning it directly toward the sun as described by Dechales and Lieberkühn. *Sl,* rays of the sun; *D,* diaphragm or hole in the shutter; *O,* object; *Ob,* objective; *I,* inverted image.

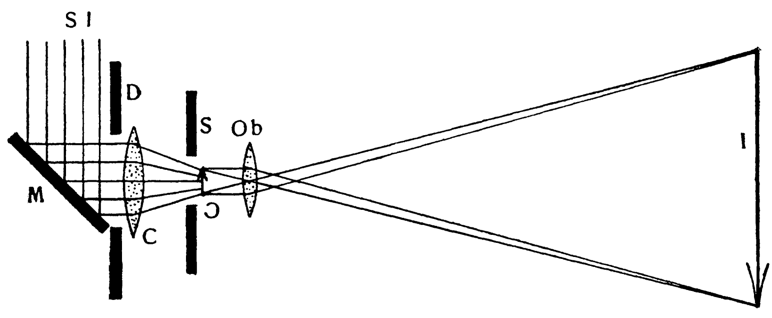

Fig. 8. Diagram of the projection microscope or magic lantern in which the apparatus remains stationary and the sun's rays are reflected into it by means of a plane mirror. This shows also the presence of a condensing lens to concentrate the wide beam of light from the plane mirror upon the object. *Sl,* sunlight striking the plane mirror (*M*) and being reflected through the hole in the shutter (*D*) to the condenser (*C*) and through the stage (*S*) to the object (*O*). *Ob,* objective; *I,* inverted image.

The instrument was set up on the sunny side, on the south if possible, and the mirror elevated and turned to the right or left to catch the sun's rays and reflect them in the desired direction. A circular motion was given the mirror to counterbalance the earth's

rotation by turning the mirror directly or indirectly by a worm-screw, rack and pinion or some other means inside the shutter.

Instead of a mirror to be moved by hand a heliostat is now frequently employed and the reflection of the sun's rays is held constant in the desired direction by the clock-work of the heliostat. There is no doubt about the superiority of sunlight for illumination with the projection microscope. All other lights appear weak beside it. As the sunlight is not to be depended upon in many parts of the world, and of course is not available in the evening when many lectures must be given, great effort has been made to find a substitute. Lamps burning various forms of oil have been and still are used. Such light is naturally vastly inferior to sunlight. An artificial light approximating sunlight in brightness was the great desideratum. In 1801 Dr. Robert Hare of Philadelphia opened the way to the discovery of such a light by the invention of the oxyhydrogen blow-pipe, by means of which a much greater heat could be obtained than in any way previously known. Dr. Hare also pointed out that in striking contrast with a flame of oxygen and carbon, the flame of burning oxygen and hydrogen is not in itself brilliant, and adds in a note: "The inferiority of the light emitted by the flame of the hydrogen and oxygen gases to that which irradiates from bodies exposed to its action, adds one to the many instances in combustion in which the quantity and color of the light do not seem to be so much dependent on the quantity of oxygen gas consumed as on the nature of the substance heated or burned."[1]

[1]Hare, Robert, Jr. Memoir on the supply and application of the blow-pipe. Philosophical Magazine, xiv (1802): 238-245; 298-306, pl. vi. Also Annal. de Chemie, xlv (1802); 113-138. In this memoir Dr. Hare describes his invention of the oxy-hydrogen blow-pipe, and discusses the comparative heat obtained by it and by other means, and says, p. 301, "More caloric ought to be extricated by this than by any other combustion." On p. 303, with reference to the light and heat: "However, it is worthy of notice that the light and heat of this combustion do not become evident until some body is exposed to it from which light may be reflected or on which the effect of the heat may be visible. This is not the case with combustion supported by oxygen and carbon."

Within twenty years after the invention of the oxyhydrogen blow-pipe by Hare, experiments with it showing the intense heat and the splendor of light produced by it when the flame was directed against refractory bodies like lime became a part of the best chemical courses, as for example those of Brande and Faraday given at the Royal Institute in London.

The real discoverer of the lime light was then Dr. Hare; but I have not been able to find out who first utilized the light for illumination. According to Andrew Pritchard in the *Micrographia* of Goring and Pritchard, the oxyhydrogen or lime light was used by Birkbeck in 1824 with a large magic lantern to illustrate a lecture on optical instruments at the London Mechanics Institution.[2] J. T. Cooper, an eminent chemist, assisted Mr. Birkbeck at the lecture. In 1832 this same Dr. Cooper was giving public exhibitions with a projection microscope, using the oxyhydrogen or lime light as a radiant.

Capt. Drummond, a young Scotch engineer engaged in the trigonometric survey of Great Britain, attended the lectures of Brande

[2]According to Andrew Pritchard (Goring and Pritchard's *Micrographia,* pp. 170-171). "The oxyhydrogen microscope so attractingly exhibited in the present day, and unquestionably meriting all the encouragement that can possibly be bestowed upon it by the promoters of rational instruction, may be defined to be a mere modification of the solar [microscope] adapted to receive, and employ to the greatest advantage, the rays of an artificial light diverging from a central point, instead of the parallel rays from the sun. In the year 1824, Dr. Birkbeck delivered two lectures on optical instruments at the London Mechanics' Institution; in one of which he took occasion to delineate on a screen, by means of a large magic lantern, representations of magnified objects intensely illuminated by the light emitted during the combustion of lime by hydrogen and oxygen gases, and to indicate the practicability of applying successfully this method of illumination to the microscope. I would not omit, however, to mention, that, about the same time, Mr. Woodward instituted some experiments with the phantasmagoria, where the light was obtained in the same way. In the interval between that and the present time [1824 and 1837], various amateurs and artists have studiously exercised their talents in perfecting the several parts of the instrument, which, like the solar [microscope] assumes its name from the source whence the light requisite to its action is derived [oxyhydrogen gas microscope]." In a note, p. 171, Pritchard says "Mr. Cooper assisted Dr. Birkbeck in this experiment [with the lime light]."

and Faraday and saw the brilliant light produced by intense heat on lime. He conceived the idea of using such a light for signaling in this survey work, and in 1826 published in the Philos. Trans. Roy. Soc., p. 324, the method of producing a brilliant light by the use of an alcohol and oxygen flame directed against lime. In 1830 (Philos. Trans. Roy. Soc., p. 383) he abandoned the alcohol and adopted the oxyhydrogen blow-pipe for heating the lime. This brilliant light was applied by Drummond to light houses. From the importance and publicity of this application of the lime light by Drummond it came to be called the Drummond light, although he was not the discoverer of the light, and it had been adapted to magic lantern illumination six years before he applied it to light houses. On the Continent the lime light was also much used for the projection microscope.[1]

[1]As a further note on the history of the projection microscope in England, and especially the development of the oxyhydrogen gas microscope the following, from the Microscopic Journal and Structural Record, vol. I (1841), is appended: "A brief sketch of the rise and progress of microscopic science, and the principal means enumerated which have tended to its general advancement.—By the Editor, Dr. Daniel Cooper.

"The first and most important attempt to develop to the public gaze the microscope on a large scale, was made by Mr. Carpenter of Regent St., who for many years exhibited a solar microscope for the gratification of the public. The uncertainty, however, of the weather and the state of the atmosphere generally in this country, and more especially in the metropolis, was the great obstacle to this exhibition. This difficulty, at first sight insurmountable, was at length overcome by Mr. J. T. Cooper [eminent chemist], who had for many years applied for private purposes the oxyhydrogen gases projected on lime (generally known as the oxyhydrogen light) as a means of illustrating in his laboratory and lectures many of the important facts connected with light.

"At a meeting of a few scientific friends to witness the results of some experiments with this light, at Mr. Cooper's laboratory, then at the Aldersgate street school of medicine (twelve years since, *i. e.*, in 1830), Mr. Cooper and John Carey of the Strand, feeling assured of the principle and stability of the application, proposed to apply this substitute for the solar rays to the illustration of microscopic power and accordingly arrangements were made, and a microscope constructed, adapted expressly to the peculiar nature of the light, which, as is well known, differs in many respects from that received from the sun. The first microscope (an experimental one) was opened in the Strand, in the year 1832, nearly opposite the end of Nor-

The electric arc light which, as shown by Davy (Philos. Trans. Roy. Soc., 1821), could be produced by using carbon terminals with strong currents from batteries, was also much experimented with. In 1845 Donné and Foucault constructed a hand-feed electric lamp to hold the carbons and Chevalier adapted a projection microscope for use with it. Owing to the difficulty of keeping the light at a uniform intensity with this lamp, efforts were made to construct one in which the distance between the carbon terminals and consequently the length of the electric arc should remain practically constant. Such so-called automatic arc lamps were constructed in 1848, 1849 and 1850 in both England and France. While the automatic lamps are very convenient, even at the present day many workers prefer the hand-feed lamps, as they are not so liable to get out of order.

In the original arc lamps the carbons were vertical as in ordinary street lamps. For general lighting this answers very well, but for

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folk street; this spot was selected on account of the contiguity to Mr. Carey's workshops as a matter of convenience only. When by dint of much time and experimental application Messrs. Cooper and Carey had accomplished their labors to their satisfaction, the scientific public, it will be remembered, were invited to attend at 21 Old Bond street, on the 18th of February, 1833, to witness the first public exhibition of the kind ever presented, in which the oxy-hydrogen light was made to perform all that had been hitherto effected with direct solar light [for the projection microscope]; and it is but justice to those gentlemen to affirm that this exhibition was considered to be, both by scientific men and the public at large, not only most creditable to the labors of the projectors, but the most interesting and important that had ever been offered to the public, and which could not fail to attract the attention of persons in every age, rank and station in life; but by possessing the noble aim of enlarging the views of the multitude by drawing their attention to the wonderful and beautiful adaptations of nature to secure her end. No exhibition was for a period better attended than was this; others in the course of a short time sprang up in various parts of the metropolis and the provinces, and two are even daily exhibited at the galleries of Practical Science in London, forming the leading attraction, and exciting the general interest and amusement of those who visit these institutions.

"The application then of the hydro-oxygen light to microscopic purposes by Messrs. Cooper and Carey in place of the very uncertain means (solar light) by Mr. Carpenter, **created at this period a *very general* taste for microscopic science."**

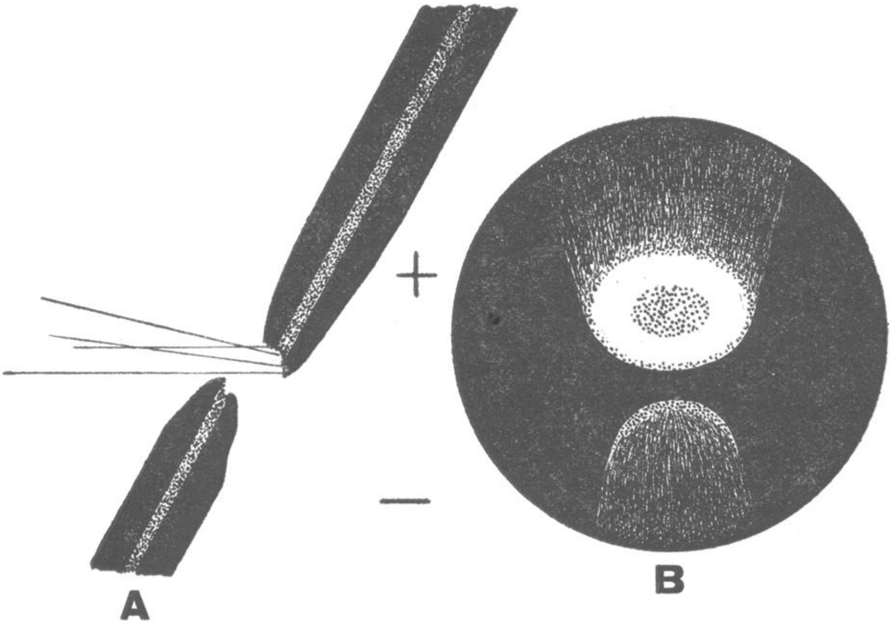

Fig. 9. Front and side views of the carbons of an arc light with inclined carbons; + and — indicate the positive and negative poles. Compare fig. 17 and pl. v.

A is a side view showing the carbons in section at an angle of 30 degrees from the vertical and the negative (—) or lower carbon slightly in front of the positive (+) or upper carbon. The carbons have soft cores.

B is a front view of the carbons as seen projected on the screen with a 42 mm. objective. It is a projection image of the carbons. This figure shows that the source of light is the crater in the positive (+) or upper carbon; it shows also that the lower carbon is slightly below the upper carbon as well as slightly in front. This avoids a shadow from the lower carbon.

In the center of the crater is shown a slight shadow. This is due to the pit formed in the soft core of the carbon.

the magic lantern or the projection microscope much light is lost. To overcome this defect concave or parabolic reflectors have been used as in the early forms with oil lamps (fig. 6; pl. II). Every position of the carbons was tried and many careful experiments made for determining that best suited for the projection microscope. An angular position was found advantageous by Lewis Wright, who induced a London maker to construct a lamp for him with the carbons at an angle of 30 to 40 degrees from the vertical (fig. 9). Finally Mr. Albert T. Thompson of Boston employed (1894) carbons at a right angle in his arc lamps (fig. 10). In lamps with

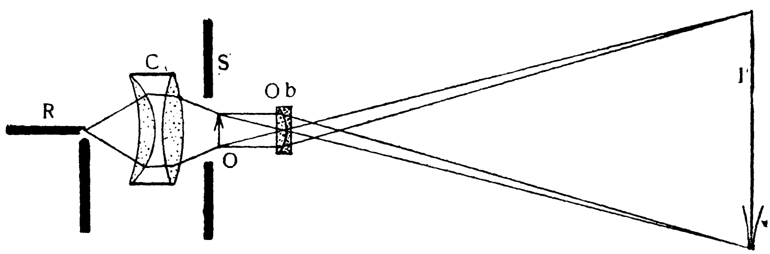

Fig. 10. Diagram of a simple arrangement for projection. *R*, right-angled carbons with the illuminating crater in the upper carbon; *C*, condenser, the first lens being a meniscus; *S*, stage; *O*, object; *Ob*, objective; *I*, inverted image. There is no water-bath either with the condenser or the stage.

the carbons at an angle of 30 to 40 degrees and at right angles the current should always pass from the upper to the lower carbon, thus giving the brilliant crater in the upper carbon, that is in a position whence the light extends most directly to the condenser. Lamps with right-angled carbons are being used more and more for projection.[1]

[1]The following is the statement of Mr. Albert T. Thompson concerning the 90° arrangement of the carbons in an arc lamp for the magic lantern:

BOSTON, Dec. 6, 1907.

"Replying to your valued communication of the 2d, I will state that I first manufactured the 90° arc lamps in 1894 and a careful search of all arc lamp and stereopticon catalogs published about that period, fails to show arc lamps of the 90° construction.

As the crater in the horizontal carbon is the source of light it is desirable that it should be equally luminous at all times with a given current, and it should have a constant position. With a given current the equal luminosity depends on the length of the arc. In hand-feed lamps this simply requires the proper amount of attention on the part of the operator. In the automatic form the device for striking the arc when the current is turned on should retain the upper carbon in the horizontal position. A device for automatically striking the arc and retaining always the horizontal position of the upper carbon was worked out and applied to his lecture room lamps of the Thompson pattern, by Prof. Wm. A. Anthony of the Cooper Union, New York. In the picture of his lamp (pl. IV, B), this device is shown by his permission. The arc-striking device is formed by links giving a hinge or parallel motion.

For microscopic and ordinary lantern projection, and especially for high power work, it is exceedingly desirable that the crater, which is the source of light, should remain in a fixed position. With solid carbons it shifts around the end of the positive carbon more or less. To avoid this soft-cored carbons were devised. The soft core seems to serve as a kind of guide, and the crater remains much more constant in position than with the solid ones.

The modern arc lamp is a source of light which serves for the projection microscope very well. While not as brilliant as sunlight, the results are so uniform and the light so ready at hand at all hours of the day or night that it has practically superseded all other radiants.

For the magic lantern the alternating current is fairly satisfactory, but more or less noisy. For both the magic lantern and the projection microscope the constant or direct current is much to be preferred. For micro-projection if one cannot use sunlight or the

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"I did not patent the lamp, for at that time there was no demand for them, and of course it was difficult to look into the future and realize that in a few years thousands and thousands would be sold.

"The facts to the best of my knowledge and belief were never published in any scientific journal. . . .

Yours very truly,

A. T. Thompson."

constant current electric light it is hardly worth while going to the trouble and expense of installing the necessary apparatus.

Condensers

In the earliest magic lanterns the light was concentrated upon the object by a concave mirror or by means of a convex lens called a condenser. With sunlight a condenser was often omitted, the sunlight being allowed to fall directly upon the object (fig. 5; pl. 1). In the more modern forms of apparatus dating from the time of Fahrenheit, Lieberkühn, Baker, Adams, Goring and Pritchard, Chevalier, etc., some form of condenser for concentrating the light upon the object was practically always used, whatever might be the source of light. In the early form the condenser was usually a simple convex lens. With the fuller possibility of rendering lenses achromatic great pains were taken to make the condensers as nearly achromatic as possible. It was well understood too that in changing from sunlight to artificial light of any kind a different form of condenser was necessary. If a single lens or combination is used for sunlight with its practically parallel rays, an artificial light with divergent rays requires at least two lenses, the one next the light to collect and render the divergent rays from the radiant approximately parallel and another lens or combination to concentrate the rays upon the object. Several forms are shown in the accompanying figures. The one composed of two plano-convex lenses with the

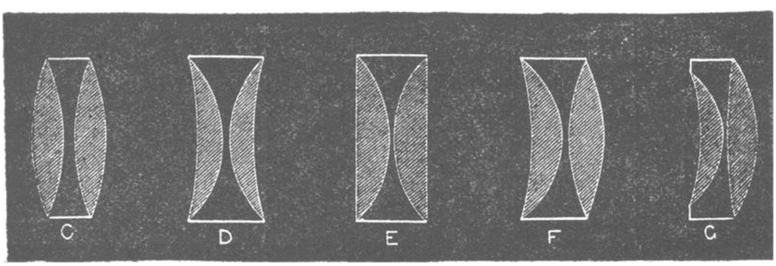

Fig. 11. Various forms of condensers. From Lewis Wright, Optical Projection. The form *E* is very commonly employed.

convex surfaces facing each other is common (fig. 11). At present there is much used a condenser of the Zeiss' pattern consisting of

three lenses: a meniscus with the concavity next the radiant and the other two lenses plano-convex with their convex surfaces facing each other as in the one just mentioned (figs. 12, 17). Such a system requires a near approach of the meniscus to the radiant (8-10 centimeters) and there is danger of breaking the lens unless it is mounted with especial care. Pritchard (1837) recommends a plate of mica between the first lens and the radiant to avoid breakage. Mica is not perfectly homogeneous and transparent and so lessens somewhat the brilliancy of the light, but it seems to be effective, as it gives time for the more gradual heating of the meniscus (fig. 12). Mica is still often used to protect the condenser.

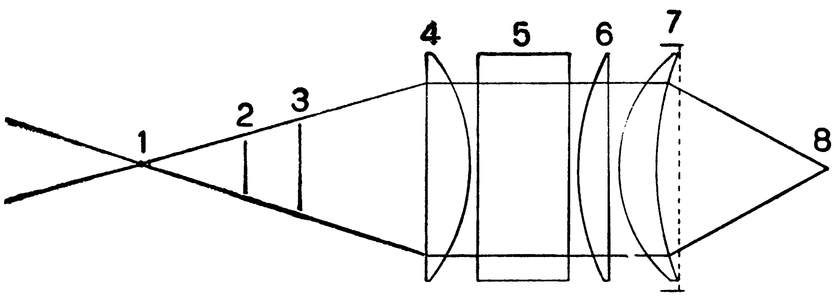

Fig. 12. To show the elements of the illuminating and condensing apparatus used in fig. 12, pl. V, A, B, and the position in the cone of light of objects of various sizes. This figure shows the necessity of moving the stage to accommodate objects of various sizes and ensure their complete illumination by the entire cone of light from the condenser. 1, focus of the condenser where objects for high powers are placed; 2, 3, position of larger objects; 4, front lens of the condenser; 5, condenser water-bath; 6, 7, two lenses of the condenser next the radiant; 8, the dotted line over the meniscus represents the sheet of mica which serves to prevent the too rapid heating of the lenses. This is very satisfactorily held in position by a cap of sheet iron or copper.

In the earlier forms of projection microscopes the object was put somewhere in the cone of light made by the condenser, depending of course on the size of the object and the objective used (fig. 12).

Substage Condenser.—In the fourth edition of George Adams' *Micrographia* (1771, pp. VII-VIII) he describes as a "principal im-

provement in the solar microscope" a secondary condenser placed very near the object. His son in his Essays on the Microscope (1787) figures this secondary, or as it is now called substage, condenser (figs. 14, 18; pl. IV, A). A substage condenser is recommended also by Goring (1837) and he advocates in strong terms that it should be achromatic, as do also Brewster and many others. At the present day the Abbé substage condenser and sometimes also a special achromatic form are often used. By some a more elaborate system still is advocated, *viz.*, a plano-concave lens in the path of the converging cone to make the rays parallel, and then a substage condenser to concentrate these parallelized rays upon the object (fig. 13).

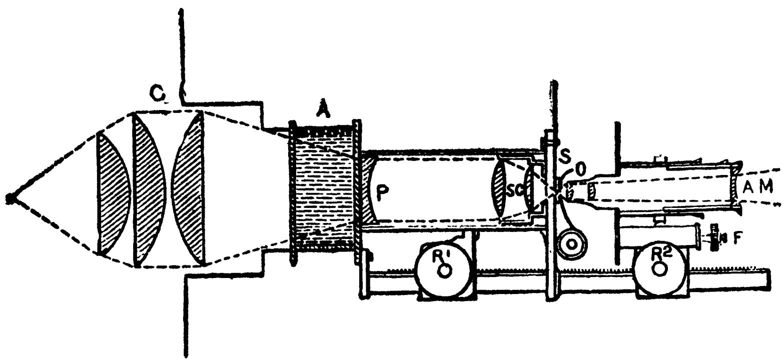

Fig. 13. Wright's Projection Microscope. C, condenser of three lenses; *A*, alum or water cell for removing the radiant heat; *P*, plano-concave of highly dispersive glass correcting largely the aberrations of the condenser, and rendering the beam parallel; *SC*, substage condenser (for low powers but a single lens is used) ; *S*, stage; *O*, object—next the object is the objective, and at the end of the tube is an amplifier, *AM*; R^1, rack and pinion for focusing the condenser; R^2, coarse adjustment of the microscope; *F*, fine adjustment of the microscope.

In my own experience, although several forms of substage condenser have been thoroughly tested, the projection microscope has been more successful without a substage condenser. Furthermore the substage condenser prohibits the use of a proper stage water-

bath for keeping the specimens cool (figs. 16, 17), and greatly limits the size of objects which can be projected.

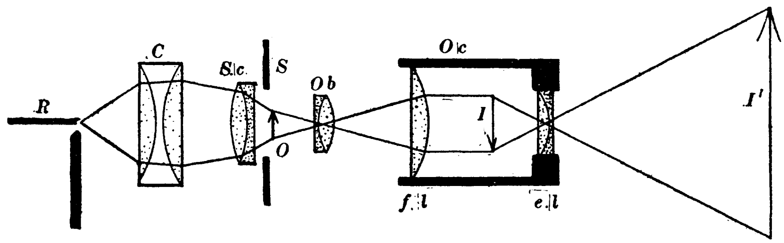

Fig. 14. Projection Microscope with substage condenser and ocular showing that the substage condenser shortens the cone of the main condenser, and that the field lens of the ocular acts with the objective to produce a real image, and that the eye-lens or combination projects this real image on the screen. As the objective inverts the object, so the eye-lens inverts the real image and the final screen image is erect like the object. *R*, radiant—in this case an arc lamp with right-angled carbons; *C*, condenser, consisting of two plano-convex lenses with the convexities facing each other; *Sc*, substage condenser. This brings the rays to a focus sooner than the main condenser would focus them. This shortening of the condensation cone enables one to shorten the apparatus, as the object can be brought closer to the main condenser. *S*, stage; *O*, object; *Ob*, objective; *Oc*, ocular, with the field-lens (*fl*) aiding the objective in the formation of a real image (*I*), and the eye-lens (*el*) serving as a second objective to project the real image as the final erect screen image (I^1).

Removal of Heat

The early users of the projection microscope with sunlight discovered that living objects were soon killed in the concentrated cone of light used to illuminate them, and that delicate objects were liable to be destroyed. In the works of Baker (1744-1785) and Adams (1746-1785) their directions for using the solar microscope caution the operator not to put living and delicate objects in the focus of the illuminating cone, but to put them in the cone before the focus is reached.

In 1837 Goring and Pritchard took a very important step in advance by advocating that the delicate living things, when shown by the projection microscope, be mounted in plenty of water, and

that a water-bath be placed in the cone of light from the sun or the lime light.

They also recommend that the slide containing the delicate living objects in water be placed just in front of the water-bath, and remark that in this way the heat is greatly reduced. At about this time Melloni published his important paper "On the free transmission of radiant heat through different solid and liquid bodies" (Ann. de Chem. et de Physique, LIII:1 and LV:337). It was shown that alum absorbs about 90% of the heat. Solutions of alum are also found to absorb most of the heat. From that time onward solutions of alum were interposed between the radiant and object to remove the heat. It is interesting to note that the first heat absorbing bath used by Pritchard was water. As the careful thermometric experiments of E. Nichols have shown (Physical Review, I:14; 1893), water is a better absorber of radiant heat than solutions of alum. It is also far less troublesome, and is now almost always used.

With the great impulse to employ the projection microscope which came in with the electric light there was naturally a much greater number of workers striving to perfect the instrument and render it applicable to the needs of a modern department of biology. One of the difficulties mentioned by the older observers still remained, and delicate and living objects were injured in spite of the condenser water-bath put in the course of the illuminating cone (fig. 12). With the perfecting of condensers the light was also more exactly brought to a focus. This made the use of great magnification possible but at the same time that the light was focused the heat rays were also greatly concentrated, and so many passed through the water-bath that delicate and living objects could be studied and exhibited with high powers for only a very short time. Fortunately the living things to be studied are mostly mounted in water and this serves as a special heat absorber. For many preparations, however, there is no such protection and they are soon ruined, as every one knows who has undertaken this kind of microscopic demonstration.

To overcome the difficulties incident to the presence of much radiant heat with high powers when the object must be nearly in the apex of the illuminating cone, Selenka (1887) used a blast of

air from a rubber bag to cool the specimen while it was under observation. Carbon dioxid has also been proposed, but so far as I know has never been actually utilized for the purpose.

In 1893 Zoth (Zeit. wiss. Mikr., p. 154) adapted and modified a Stricker's warm stage to keep the slide cool by direct conduction as well as by absorption, by circulating cold water in the apparatus instead of warm. This is a realization for modern conditions of what Pritchard and others secured in their time by mounting the specimens in water, and is more generally applicable as not everything can be put in water. Leitz, to avoid the necessity of circulating water, used a stage water-bath with a neck-like process extending through the stage to the level where the slide rests (fig. 15).

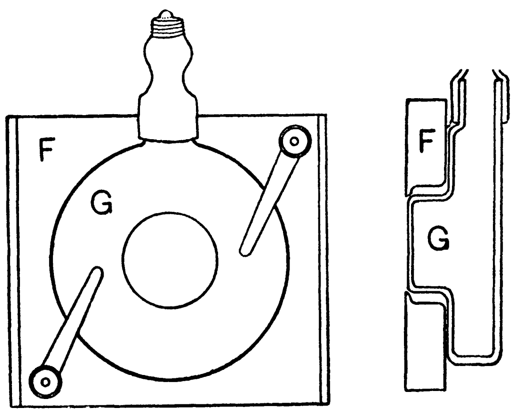

Fig. 15. Letiz's stage water-bath. In A it is shown below the stage; in B it is shown in section. *F*, stage; *G*, water-bath. It is held in place by springs.

In 1904-5, after using Leitz' specimen cooler, the writer became convinced that the cooling of specimens by conduction was of as great or greater importance than the absorption of the radiant heat by the stage water-bath.

As it is necessary in a biologic laboratory to project objects of greater length than the usual diameter of the stage opening, a stage

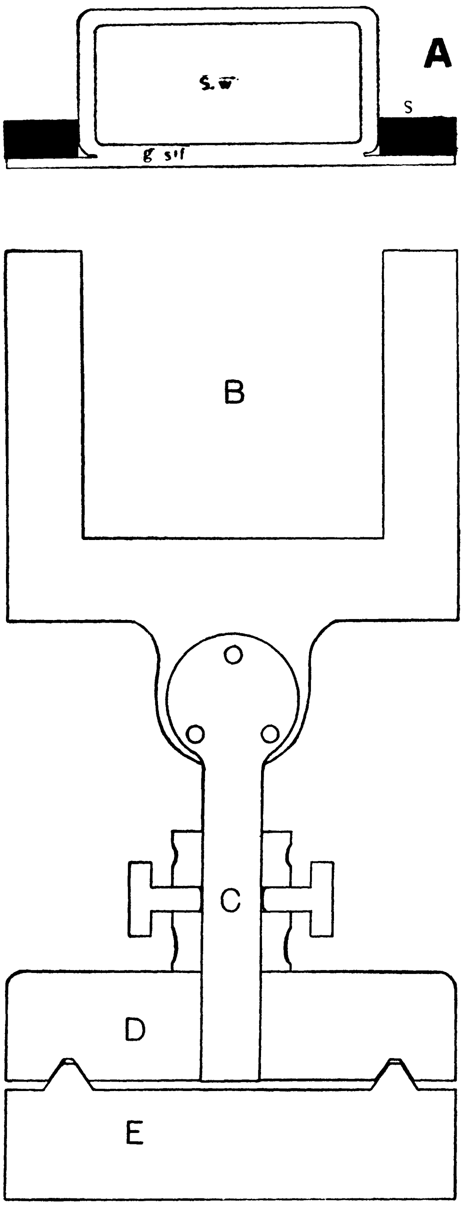

FIG. 16, A. Sectional view of the stage with the stage water-bath. *S*, stage in section; *Sw*, stage water-bath; *gsf*, glass front for the stage. It has attached to it the stage water-bath.

FIG. 16, B. Opening in the stage 8 centimeters square; *C*, stem of the stage in the socket of the sliding piece (*D*); *E*, sectional view of the lathe bed with its V's to fit the grooves of the sliding pieces supporting the condenser, stage and microscope. See pl. V, A and B.

water-bath like that in the accompanying figure (fig. 16) was devised. It is of sufficient size to fulfill the requirements of modern projection; *viz.,* from objects near the size of lantern slides downward to the smallest that can be successfully shown (fig. 16, A). The front is of the full size of the stage. It is made by cementing with Canada balsam a piece of glass to an oblong museum jar about 75 mm. wide, 75 mm. high and 37 mm. thick. The museum jar should of course be polished on both sides. One may have such a glass stage-front and a water-bath constructed of thin plate glass, by the fusion method employed in Germany. The slide then always rests its full length against the cool water-bath and heat is conducted away from the slide. The additional water also serves to absorb some of the radiant heat from the illuminating cone. Such a combination of condenser water-bath and stage water-bath answers for nearly all purposes. For a uniform and more complete control of the heat in the illuminating cone, Dr. Greenman, Director of the Wistar Institute of Anatomy and Biology (Anatomical Record, 1907, p. 170), has devised a condenser water-bath with a hollow jacket around it. Cold water is circulated through the jacket and serves to keep the water-bath cold. He also uses the stage water-bath for the more delicate objects and when high powers are used, especially when the objects must remain a considerable time in the field as for drawing.

Zeiss, Reichert, Beck, A. T. Thompson & Co., and others have supplied condenser water-baths in which cold water circulates in the bath itself. Strange quivering figures appear on the screen occasionally on account of the difference of density when the cold and the heated water mix.

The following table is introduced to show the heating of the condenser and the stage water-baths in actual work with different currents and in different positions of the water-baths:

TABLE SHOWING THE RISE IN TEMPERATURE OF THE TWO HEAT-ABSORBING WATER-BATHS OF THE PROJECTION MICROSCOPE SHOWN IN PLATE V

(A direct or constant current of 110 volts at the dynamo was used for all the experiments. The amperage varied as indicated in the first column of the table.)

Amperes	Time	Temperature of condenser water-bath (Cw.)	Temperature of stage water-bath (Sw.)	Position of water-baths
A 10 Amp.	Start	19° C.	19° C.	Cw. as in pl. v, B; Sw. for low power (pl. v, A)
	30 min.	35° C.	22° C.	
	1 hr.	45° C.	23.5° C.	
	1½ hr.	53° C.	25° C.	
	2 hrs.	69° C.	27.5° C.	
B 15 Amp.	Start	23° C.	23° C.	Sw. for high powers (pl. v, B)
	45 min.	64° C.	28° C.	
	2 hrs.	97° C.	36° C.	
C 15 Amp.	Start	22° C.	22° C.	Sw. for high powers; Cw. in front of the condenser
	30 min.	32.5° C.	25° C.	
	1 hr.	36° C.	26° C.	
D 20 Amp.	Start	22° C.	22° C.	Water-baths as shown in pl. v, B
	30 min.	65° C.	25° C.	
	1 hr.	91° C.	31° C.	

This table shows very clearly that the heating of the water-baths depends upon the amperage used. It also shows that the stage water-bath is heated about the same for the high power as for the low power position. The condenser water-bath is heated very much more when on the metal saddle between the lenses of the condenser than when in front of the condenser and unconnected with it.

From the arrangement of the different parts of the apparatus it is plain that the condenser water-bath must get a great deal of heat from the metal saddle on which it rests. In the less compact form of Zeiss for example where the support for the water-bath is independent and receives no heat by conduction, the water-bath will become heated only or mainly by the absorption of radiant heat from the illuminating cone. The great advantage of such a device as Dr. Greenman's for circulating cold water around the

condenser water-bath can be seen from the above table, especially in B and D, where the experiment lasted a considerable time or where the amperage is high.

It is a fact easily understood that there is great difference in objects for projection. Some colors transmit freely the radiant heat while others absorb the heat and soon the specimen is ruined. Specimens stained with carmin are especially favorable for projection. Thick sections stained with hematoxylin absorb the heat very rapidly. Osmic acid specimens are also unfavorable as they absorb much heat and can be used only for a short time, especially in high power projection.

Projection Objectives

The earliest objectives for projection were simple convex lenses. If one is inclined to underrate the results obtainable in low power magnification with them let him take any convex lens, say one of those in the cheap tripod magnifier and he will be astonished at the excellence. Of course there will appear around the edges the color fringes seen in all uncorrected lenses.

Naturally the early workers, full of enthusiasm for the projection microscope, added improvements as they arose. The early achromatic objectives (1823 and onward) were applied to the projection microscope with greater or less success, but as the apertures were rather small the loss of brilliancy seemed a greater defect than the color fringes of the uncorrected lenses. Among the first to really grasp the principles governing the projection microscope and to discuss them in a masterly way were Goring and Pritchard (1837) and Chevalier (1839). It is true that Euler, Brewster, and others had discussed from the theoretical side the application of achromatism to the projection microscope, but theory rarely works out just right in practice because so many factors not duly considered by the theorist, are sure to obtrude themselves in actual work.

In ordinary microscopic observation the curvature of the field does not greatly trouble the observer for the attention is concentrated upon a very small part of the field and the fine adjustment brings into perfect focus the part to be especially studied at any given moment. With the projection microscope the image is like a

great picture and is far more satisfactory if it is distinct over its whole extent. Then one of the greatest advantages of the projection microscope is that it shows objects as wholes. For the purposes of general morphological study as in embryology and in the study of the large sections of the nervous system for fiber tracts and relations, the large field shown by the projection microscope is its greatest advantage.

Among the first compound objectives to give good results were those made on the principle of the Ramsden oculars (Brewster, p. 109). Lewis Wright found lenses of the photographic type made on the Petzval system to work well. For large embryologic preparations, large sections of the central nervous system and other large specimens, photographic objectives of 100 to 120 mm. equivalent focus serve a good purpose, the "planars" of Zeiss giving particularly good results. For such specimens Messrs. Howland Brown and Morris Earle devised a variable objective called a mediascope to indicate its function between the ordinary lantern slide objective and microscopic objectives.

To secure flatness of field and brilliancy of image many opticians have made special objectives for projection. As early as 1874 Zentmayer produced excellent ones. They had the metal mounting blackened outside as well as inside so that there should be no confusion arising from internal reflections and no blinding the eyes of the operator by reflection from polished surfaces on the outside.

Many opticians now produce excellent projection objectives. They are sometimes adapted only for the projection microscope, but more often they are adapted for both screen projection and for photo-micrography. The projection objectives of higher power than about 10 mm. equivalent focus have not proved satisfactory in my hands. For all powers, and especially for the higher ones, objectives for ordinary microscopic work are used. Not all objectives which answer well for ordinary microscopic use are satisfactory for projection. One must test many and select those best adapted for the work. As stated by Lewis Wright, the price of the objective is no guide to its excellence for projection.

Use of Oculars

The objectives prepared for ordinary use are corrected to give a real image at a distance of 160 or 250 mm., and it could hardly be expected that they would give equally good real images on a screen at a distance of 5 to 10 meters. To use these objectives for projection and preserve the conditions for which they were corrected many workers use oculars. When the ocular is used if it is Huygenian in form or any form of negative ocular, the field-glass acts with the objective to form a real image, then the eye-glass or lens at the upper end of the ocular acts like another objective to project the real image upon the screen. If the Huygenian ocular is used the final image on the screen is formed by a simple convex lens. Whatever the form of ocular the screen image is erect as the objective inverts the first image and the ocular inverts the real inverted image, restoring it to its original position. To fully appreciate this one must have a translucent screen like ground glass and look at the back of it, otherwise the image will look as it does when looking on the wrong side of a printed sheet.

For photographic and projection work Zeiss devised a special projection ocular in which the upper or eye lens is a corrected combination. This gives more perfect screen images than a simple lens such as is found in an ordinary ocular (fig. 14).

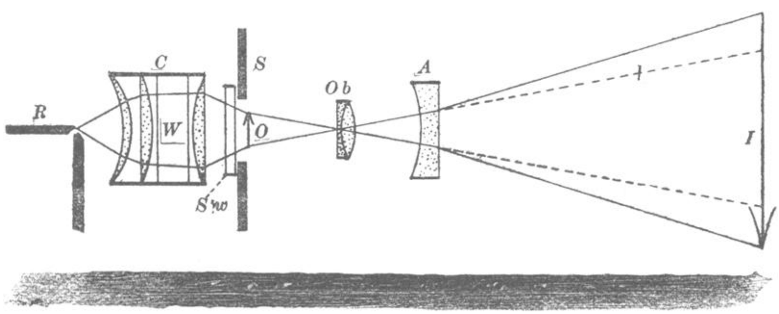

Fig. 17. Diagram of a projection microscope with a triple lens condenser (*C*) with water-bath (*W*) ; a stage water-bath (*Sw*), and an amplifier (*A*). The dotted lines indicate the course of the outer rays if no amplifier were used. *R*, radiant; *S*, stage; *O*, object; *Ob*, objective.

The difficulty with all forms of oculars is that the brilliancy of the image is much lessened, but the greatest defect is the restriction of the field of view. A large field is one of the greatest benefits afforded by the projection microscope, but the ocular does away with that advantage, and the object must be moved to bring in small fields in succession as with the ordinary microscope.

AMPLIFIER

Among the numberless experiments tried in the early development period of the microscope some one hit upon the idea of employing a concave lens above the objective to diverge the rays and therefore to increase the magnification (figs. 17, 18), hence the name "amplifier."

According to Petri (p. 136), Conradi, 1710, used a double concave lens above the objective. In the achromatic microscope of Selligue, as made by Chevalier, 1823-24, there are two draw-tubes. In the upper of these is the ocular and in the lower a biconcave amplifier. Two such lenses were furnished with the microscope for different powers.

In the projection microscope made and figured by Chevalier, 1839, an achromatic combination is used as an amplifier (fig. 18).

As shown in the accompanying figure from Wright, he also employed an amplifier consisting of a plano-concave lens at the end of the short tube of the projection microscope, no ocular being used (fig. 13).

For ordinary demonstration purposes the author has found the amplifiers —5 diopters and —10 diopters a great addition to the accessories of the projection microscope. With the —5 diopter amplifier the size is increased about one-half, and with the —10 diopter amplifier about once, making the images one and one-half and twice the size that they are when only the objective is used. To get this amplification with objectives would lessen the light greatly and also cut down the field; the use of oculars would also reduce the light greatly and cut down the field still more. (See under the 8 mm. objective in the following table; see also pl. Va.)

TABLE SHOWING WHAT CAN BE DONE WITH THE PROJECTION MICROSCOPE SHOWN IN PL. V, A AND B, WITH A SCREEN DISTANCE OF 8 METERS, A DIRECT CURRENT OF 110 VOLTS AT THE DYNAMO, AND THE AMMETER, BY THE PROJECTION APPARATUS READING 12 TO 15 AMPERES

Objective	Ocular	Amplifier	Field	Magnification	Screen image	Remarks
105 mm.	None	None	50-60 mm.	× 80	4000 mm.	No tube pl. V, A
75 mm.	None	None	70 mm.	× 105	7350 mm.	" "
Planar 50 mm.	None	None	45 mm.	× 160	7200 mm.	" "
Planar 30 mm.	None	None	13 mm.	× 260	3380 mm.	Tube as in pl. V, B
30 mm.	None	— 5 d.	13 mm.	× 390	5000 mm.	" "
30 mm.	None	—10 d.	13 mm.	× 520	6760 mm.	" "
12.5 mm.	None	None	4.5 mm.	× 600	2700 mm.	" "
12.5 mm.	None	— 5. d.	4.5 mm.	× 900 +	4050 mm.	" "
12.5 mm.	None	—10 d.	4.5 mm.	× 1200+	5400 mm.	" "
8 mm.	None	None	2.6 mm.	× 990	2574 mm.	" "
8 mm.	Proj. x2	None	0.6 mm.	× 2000	1200 mm.	Narrow tube
8 mm.	Proj. x4	None	0.6 mm.	× 4000	2400 mm.	" "
8 mm.	None	— 5 d.	2.6 mm.	× 1485	3861 mm.	Tube as in pl. V, B
8 mm.	None	—10 d.	2.6 mm.	× 2000	5200 mm.	" "
2 mm. Hom. Im.	None	None	0.5375 mm.	× 4000	2150 mm.	" "

SCREEN

From the earliest use of the magic lantern it was recognized that a white screen made of cloth or a whitewashed wall was desirable (see quotations from Porta). Translucent screens were also used. These were made of ground glass or of oiled cloth. Then the lantern could be entirely out of sight of the audience. This was of course necessary for the striking exhibitions of the phantasmagoric magic lantern. Even at the present day ground glass screens are sometimes used for lecture purposes. In such cases the apparatus is eliminated from the lecture-room.

Baker (1742-1785) recommends a screen made of "the largest elephant paper" stretched on a frame like that used for fire screens. Adams (1746-1771) recommends the same kind of screen. Both recommend for a large screen, one made by pasting several sheets of the elephant paper on cloth. The screen is then let down from the ceiling like a roller map.

Pritchard, 1837, gives in a few words the requisites of a good screen for projection purposes: "It should be smooth, white and opaque; it should reflect the greatest quantity of light and absorb the least." He advocates among other things screens made of plaster of Paris or a wall with a thin coat of plaster of Paris spread upon it. Lewis Wright also speaks well of plaster of Paris screens. From my own experience a smooth wall with a wash of plaster of Paris forms the best screen for micro-projection. Such a screen fulfills the requirements given for a screen by Pritchard. For the highest powers a small screen made by flowing a thin layer of plaster of Paris on a perfectly clean plate glass gives the most perfect results. In making the screen a frame with wire netting is placed on the glass and the plaster of Paris poured on until the wire is covered and the frame filled with the plaster. After the plaster has set and partly dried there is no difficulty in removing it from the glass.

Large bristol board sheets with a smooth, lusterless white surface also serve well. The coated roller screens now on the market are good for general work, but the surface is too rough for the most satisfactory micro-projection.

Screen Distance.—With lamp light or even with the lime light the screen distance cannot be very great or the projected images will be too faint. With sunlight and the electric light, the screen distance is almost unrestricted. For ordinary projection with a current of 12 to 15 amperes and objectives up to 6 mm. equivalent focus, a screen distance of 7 to 10 meters gives good effects. Everything that can be shown well can be made large enough so that each person in an audience of 200 to 500 can see with satisfaction.

For the higher powers (3 mm., 2½ mm., 2 mm. objectives), a screen distance of 3 to 5 meters is more satisfactory, and the spectators must be few and close to the screen or they must use opera glasses. For objects requiring high powers, 2½ or 2 mm. objectives, it is far more satisfactory to use compound microscopes in the ordinary way.[1] The writer has not found projection of details

[1]For example the oval red blood corpuscles of the camel were 25 mm. long with a 2 mm. homogeneous immersion objective and a screen distance of 3 meters; but the screen picture was far less satisfactory than the image of the same corpuscles seen under the microscope.

satisfactory which could not be seen with a compound microscope supplied with a low ocular and a 16 mm. objective. For such objects the projection microscope shows them on the screen as satisfactorily for 500 as the compound microscope shows them to a single individual.

Darkening the Room for Projection

From the earliest experiments with projection (see note from Porta), the effect was known to depend largely on the darkness of the room where the projection took place. It was for this reason, in part, that the evening was so often selected for lantern exhibitions. Baker (1742-1785) says: "When this microscope is employed the room must be rendered as dark as possible, for on the darkness of the room and the brightness of the sunshine [or other light] depend the sharpness and perfection of your image." Pritchard goes further and would have everything in the projecting room dark except the screen. This is often done in rooms for drawing with the projection microscope.

With a magic lantern for lantern slides and the powerful modern electric light the room does not need to be very dark, but for micro-projection unless it is very dark the screen image will have a gray appearance and lack in crispness.

Mechanical Parts

With every increase in complexity of the projection microscope and its work, the mechanical parts must keep pace. Naturally the earliest forms were very simple (fig. 6; pls. I and II).

The construction and arrangement to meet the increasing requirements have been worked out very differently by different ones. The diagrams (figs. 5, 7, 8, 10, 14 and 17) represent fairly well the composition and arrangement of the different optical and mechanical parts in different cases. There is, it seems to me, one fundamental requisite, *viz.*, that each part should be independent and so mounted that it may be easily adjusted to work most effectively with the other parts. That is the radiant, the condenser, the water-bath, the stage with its water-bath or condenser, and finally the projection

objective with the focusing arrangement should all be separate and separately adjustable. They should also be on some kind of lathe bed or guide so that they may all be moved back and forth in a longitudinal direction without getting out of line. In a very simple form (fig. 6), where no great variety of work is demanded all the parts may be more closely united, but it is very restrictive to have them so united in modern apparatus. For compactness it is of great advantage to have the water-bath on the same support as the condenser lenses, but as shown by the table above, the water-bath is greatly heated by conduction from the lamp as well as by the absorption of radiant heat. The apparatus may be more compact with the stage and tube and focusing device in one piece as with an ordinary compound microscope, but unless the coarse adjustment has a very long rack for focusing it is impossible to arrange the object and the objective in the position giving the best results in the projected image.

In the earlier editions (4th, 1899) of Zeiss' catalog of projection apparatus, there is one, the so-called simplified projection apparatus which fulfills the above requirements, because each piece is independent and all are arranged on a kind of lathe bed, and one may easily pass from high power projection to that of objects 25 to 30 mm. in diameter. The one presented in pl. V, A, B, closely approximates the best construction. The contact of the condenser water-bath with the metal part of the condenser holder is objectionable as the water-bath is heated by direct conduction (see table above).

One of the greatest defects is the small size of the opening in the stage. Of course no specimen larger than the stage opening can be projected. This prohibits the use of the large sections of the central nervous system necessary for understanding its morphology; it also prohibits the use of sections of organs and of large embryos, *i. e.,* objects of 25 to 60 mm.

In early projection microscopes there was no tube extending beyond the projection objective (figs. 6, 8 and pl. IV, A), therefore there was no restriction of the field from that cause, as with the relatively long and narrow tube of the ordinary compound microscope so commonly used in projection at the present day.

To avoid this restriction of the field by the tube, either no tube is used with photographic and other low objectives (pl. v, A), or for ordinary projection a very large and short tube (pl. v, B) is used, *i. e.*, one 45 to 50 mm. in diameter and 9 to 10 centimeters long. Harting, in 1839, figured and described such an arrangement. Selenka, 1887, used no tube, and Zeiss and others recommend large and short tubes like that of Harting. If projection oculars are to be used a small tube with an adapter may be attached to this large tube.

Blackening the Apparatus

As recommended by Goring and Pritchard in the *Micrographia* (1837), all the metal and exterior parts of the projection microscope should have a dead-black finish. Sunlight, the lime light, and the electric light are so brilliant that any polished surface reflects the light so strongly that the operator is almost blinded and becomes unable to focus the image on the screen properly. Much light is also reflected into the room.

Drawing with the Projection Microscope

Baker (1742-1785) describes with enthusiasm the advantages of the projection microscope for drawing[1]; Adams, father and son (1746-1787), describe the ease by which drawings can be made on vertical surfaces, including ground glass. By means of a special

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[1]Baker, Henry P., Of Microscopes and the discoveries made thereby, p. 25:

"This Microscope [the solar microscope] is the most entertaining of any; and, perhaps, the most capable of making Discoveries, in Objects that are not too opake: as it shews them much larger than can be done any other Way. There are also several Conveniences attending it, which no other Microscope can have; for the weakest eyes may use it without the least Straining or Fatigue: Numbers of People may view any Object together at the same Time, and, by pointing to the particular Parts thereof, and discoursing on what lies before them, may be able better to understand one another, and more likely to find out the Truth, than when, in other Microscopes they must peep one after another, and perhaps see the Object neither in the same light, nor the same Position. Such too as have no Skill in Drawing, may, by this contrivance, easily sketch out the exact Figure of an Object, they have a mind to preserve a Picture of; since they need only fasten a Paper upon the Screen, and trace it out thereon, either with a Pen or Pencil, as it appears before them."

camera obscura arrangement which can be set in a vertical position, the object being illuminated by sunlight, drawings can be made in a horizontal position. George Adams, Jr., devised an arrangement for drawing with the lamp or lucernal microscope also. In 1767, Brander devised a camera obscura for drawing with the solar microscope; the illuminating and projecting part being horizontal, a plane mirror reflected the image downward upon a horizontal surface where it could be drawn.

In the *Micrographia* of Goring and Pritchard, ground glass is used for a screen and drawings are made on paper in a vertical position, either on the front or the back of the screen. Working on the back of the screen has the advantage that the hands and pencil cast no shadows.

Dr. Goring describes an accessory to his solar microscope by which the light is reflected downward by means of a plane mirror or prism into a drawing box. At the bottom of the drawing box is a field curved to correspond with the curvature of the field of the microscope (see figures in the *Micrographia* and in Brewster On the Microscope, 1837).

In Chevalier's work (1839), the advantages of the projection microscope for drawing are mentioned, and he figures a prism intro-

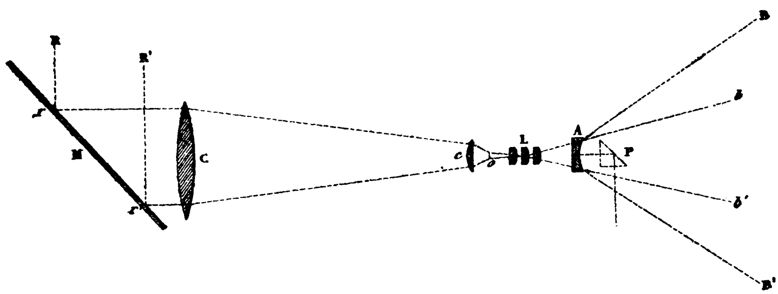


Fig. 18. Projection microscope from Chevalier (Planche 2). *M*, mirror reflecting the sun's rays (*RR'*, *rr'*) to the condenser (*C*) ; from the condenser they pass to the substage condenser (*c*) and are condensed upon the object (*o*). *L*, achromatic objective; *A*, amplifier composed of a plano-convex and a double concave lens,—this amplifier makes the rays much more divergent, *i. e.*, *BB'* instead of *bb'*; *P*, right-angled prism acting as a 45-degree mirror to project the image down upon a horizontal surface for drawing.

duced in the path of the rays to reflect them downward on a horizontal surface for drawing (fig. 18).

At the present time the projection microscope is much used for the numerous drawings necessary for making models. Sometimes the drawings are made on a vertical surface but some laboratories have also a device for reflecting the image downward upon a horizontal drawing surface. It is tiresome to draw for a considerable length of time on a vertical surface, but on a horizontal surface the drawing hand is supported and it is easier to get an exact copy. For making large diagrams of microscopical specimens one naturally uses a vertical surface.

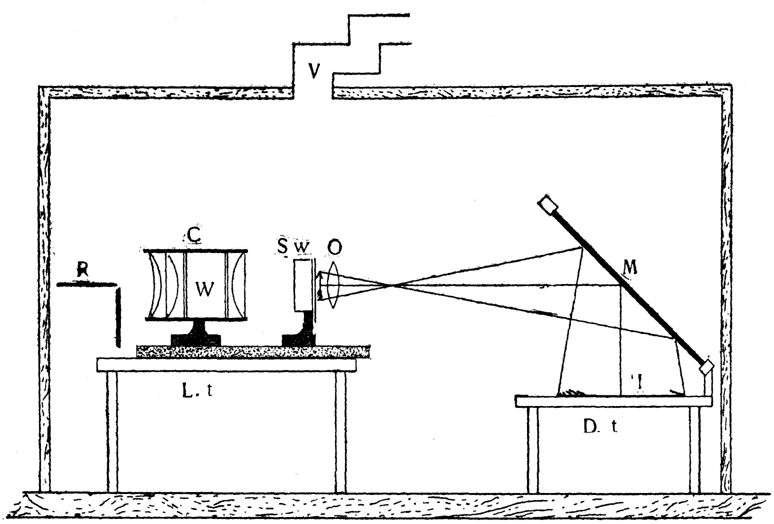


Fig. 19. Projection microscope for drawing on a horizontal surface. The optical bench carrying the radiant (*R*), the condenser and condenser water-bath (*CW*), the stage and stage water-bath (*Sw*) and the microscope (*O*), are on one table, *Lt*, and are perfectly horizontal. The drawing table, *Dt*, bears the mirror (*M*) at an angle of 45 degrees. This insures an undistorted image on the horizontal surface of the drawing table. This apparatus, and the furniture for photography are in a special cabinet about 3 meters square and 2¼ meters high, in a large room. It is painted dead black on the interior. *V*, Light-excluding ventilator.

In some institutions special rooms are set apart for drawing and for photography, for example in the Johns Hopkins medical school, the Wistar Institute for Anatomy and Biology, etc. Such rooms are usually made dead black to avoid reflections. Crisper pictures are also easier to produce under such conditions. In fig. 19 is shown a small drawing room (3x3x2¼ meters) or cabinet within a large laboratory. See also the Anatomical Record, November, 1907, where Dr. Greenman describes the drawing or photographic cabinet of the Wistar Institute. Either a special room convenient to the laboratory or some such cabinet in the laboratory is almost a necessity for the work of a modern biologic department.

Projection Microscope for Opaque Objects

In the study of modern histology and embryology the majority of the objects to be studied are lighted by transmitted light and are therefore seen as transparencies. In the earlier days before the technique of microscopic work had become developed to any great extent a large number of the objects studied were viewed as opaque objects, and all sorts of devices (bull's eye condensers, concave specula, etc.) were used to illuminate the objects. Naturally there was a great desire to show opaque as well as transparent objects by the projection microscope, and the Adamses (1746-1787) devised what they called opaque solar and lucernal microscopes. Martin (1774) is said to have produced a fairly good one. Sometime before 1756, Lieberkühn, according to Harting, devised a solar microscope for opaque objects, and Euler and his followers, Aepinus and Zeiher (1750-1779), suggested improvements for this purpose. Harting also speaks of his countryman, Hendrik Hen (1807), as having made an excellent microscope which was adapted for opaque objects and also for use as a solar microscope. In the *Micrographia* of Goring and Pritchard (1837) there are given very good figures and descriptions of a projection microscope for opaque objects adapted either for sunlight or the lime light.

Briefly stated an opaque projection microscope is one in which light from the radiant (sun or some form of lamp), instead of passing through the object and directly to the objective is received by a plane mirror, or a series of plane mirrors arranged in a circle,

or by a concave mirror and thrown upon the upper side of the opaque object. The light reflected from the surface of the object passes to the objective and the image is by it projected upon a screen as usual.

In the form devised by Adams there was a plane mirror in line of the beam of light from the radiant. The object and objective were at a higher level. The light from the plane mirror was reflected upon the object and illuminated its upper surface. More often the objective and object were in the line of the illuminating beam, but a series of small plane mirrors were arranged around the objective to reflect the light back upon the upper side of the opaque object, or a concave mirror with a hole in the middle for the objective was used for the same purpose. The perforated concave mirror is said by Harting to be due to the ingenuity of Leeuwenhoek, but its invention is often ascribed to Lieberkühn, and goes by his name.

Opaque projection is now little used with the microscope except for photographing metals and alloys in micro-metallography. The fundamental principles of Adams' apparatus have been closely followed, however, in the modern magic lantern devices known as episcopes or reflectoscopes for projecting pictures in books, various forms of mechanism, etc.

Projection and Photomicrography

One of the most important uses of projection is the production of photographs of microscopic objects. The general principles for obtaining the real images necessary in photography and for screen images are the same.

Among those who raised photography with the microscope to a high degree of perfection (1866-1876) should be mentioned, in the first place, Col. J. J. Woodward of the United States Army medical corps. His papers on the subject and the accompanying photographs form a notable landmark. In the period when the projection microscope for teaching and public exhibitions had receded into the background he and others used projection for photography and worked out with great precision the conditions of lighting, objectives, etc., upon which success depends. While he employed oculars and amplifiers for some of his work, he says in

his report (1871) on photographing histologic preparations by sunlight, that he discarded all oculars and amplifiers and got the desired magnification by the objective at the necessary distance. His photographic laboratory was a large room and the sensitive plate could be placed at any desired distance from the objective. Dr. Woodward speaks very highly of the electric light and compares it favorably with sunlight. While the interest in photo-micrography helped to keep alive the knowledge of projection, its influence on projection for public exhibitions and class-room work has not been altogether helpful, for while the general principles are the same, the best effects in photography are only obtained when sharpness with fine detail are secured, while with projection for teaching and exhibition purposes, brilliance and striking contrast are all important. The fine detail so necessary in a photograph are lost on a distant screen image.

Furthermore, in photography only a very limited field can be shown in a single picture, while in projection for teaching purposes a very large field should be available so that the relations of the various parts of the objects can be seen. It seems therefore to the writer that in striving to realize all of the excellence of a photographic image for ordinary projection work there has been a retarding effect upon projection, by a too close adherence to the conditions necessary in photography. The substage condenser so desirable in photography limits the size of the stage opening and consequently the size of the object which can be shown. It also prohibits the use of a really effective stage water-bath, and consequently makes it impossible to use delicate and living objects for a sufficiently long period. In photomicrography high powers give satisfactory results, but for projection on a screen for many observers only moderate powers are really satisfactory (100 mm. to 5 mm. objectives).

Conclusion

In tracing briefly the course of events since the first production of lenses it is seen that the enthusiasm aroused by the use of these glasses was great and enduring. To the visible forms with which nature is so abundantly endowed they revealed an abundance of invisible ones, rivalling the visible both in numbers and in beauty.

With the deep social instinct that makes men wish to share with their fellows, there came about the development of means to show these marvels of beauty and complexity to many at once, hence has been more fully perfected the *laterna magica* in its various forms during the last three hundred years.

In our own generation the interest in minute forms with beautiful markings and strange ways do not arouse the same enthusiasm as with the first observers, yet, after the introduction of the doctrine of organic evolution, they were studied with an intensity never before known in the hope that nature might perhaps in these simple forms reveal herself. Furthermore there is a widespread conviction that some personal and intimate knowledge of nature should be the heritage of every human being. Hence has come in the period of "Nature Study," and the immense improvement of laboratory architecture, and the betterment of laboratory facilities. In this advance the improvement and use of the microscope has not lagged behind. But one can hardly assert the same of the projection microscope. The simple and general pictures given by it in earlier times no longer satisfy. Now more frequently it is the definite and specific, and the minutest detail that contain the points of greatest interest.

As every individual student must repeat the history of the race in his development the wise teacher does not too rigidly insist on the minute and the specific at first, but deals with the general, and the broad relations of things.

This being true there is still a place in which the projection microscope can supply a need in instruction. This need is some method of demonstrating the forms and relations of parts in the specimens themselves. It is the need of getting back to nature in lectures and demonstrations instead of relying too exclusively on diagrams and models.

As nearly every institution now has an electric lighting plant and the ordinary magic lantern for lantern slides is almost universally used the addition of a projection microscope to the teacher's outfit is not prohibitive.

Every person installing such an outfit should know what can be reasonably expected of it, and the range of its possibilities. The modern teacher of biology, judging from my own experience, re-

quires a projection microscope which will begin where the ordinary magic lantern leaves off, and show specimens from 50 to 60 mm. in diameter to those of 1 mm. or less, and so enlarge them that they in all their details can be seen by 500 people as easily as by one looking into an ordinary microscope.

The aid which the projection microscope is capable of rendering the investigator in the preparation of drawings and in the study of the relations of structures is so great that when once fully aware of this possible help he will not willingly forego it.

Not many projection microscopes meet all the requirements given above, but that, in part at least, is because maker and user have become too much separated by modern specialization. In earlier times the user of optical instruments was also frequently the maker (Galileo, Newton, Campani, Herschel, Huygens, Hooke, Leeuwenhoek, etc.), or the optician was the friend and co-worker of the master or patron for whom the apparatus was made.

With the constant or direct electric current guaranteeing a radiant at all hours of the day, which is but little inferior to sunlight, biologists and other users of the microscope are turning again to the projection microscope and the greatest optical manufacturers in the world are taking hold of the problem in good earnest. Fortunately also many men with laboratory training and who therefore know the actual needs are coming more and more to have positions of responsibility in these great manufacturing establishments.

As with the laboratories of physics, chemistry and physiology, so in a less degree of laboratories of biology, much of the apparatus needed to work out special problems is first produced in the laboratory workshop under the direction of the one who knows best the object to be attained. Enough has been accomplished already by the laboratories and the opticians in bringing the apparatus abreast of modern requirements to show that there is a movement on foot to utilize more and more this most striking of all means of study and demonstration, and it is confidently predicted that the projection microscope will soon come to its own again.

ANNOTATED BIBLIOGRAPHY

For the better appreciation of the appearance and character of the older works consulted the entire title page is given, including the various mottoes or proverbs appended thereto.

ADAMS, GEORGE.

Micrographia illustrata: or the microscope explained in several new inventions, particularly of a new variable microscope for examining all sorts of minute objects and also of a new Camera Obscura Microscope designed for drawing all minute objects either by the light of the sun or by a lamp in winter evenings to great perfection; with a description of all the other microscopes now in use. Likewise a natural history of aerial, terrestrial and aquatic animals, &c., considered as microscopic objects. By George Adams, mathematical instrument maker to His Majesty. London, 1746, 1771.

The 4th edition of 1771 was used. It is illustrated by 72 copper plates containing 560 delineations of various microscopic objects. The title page of this work gives a very good table of contents.

ADAMS, GEORGE.

Essays on the microscope containing a practical description of the most improved microscopes, a general history of insects, their transformations, peculiar habits and œconomy; an account of the various species and singular properties of the hydrae and vorticellae; a description of 379 animalcula with a concise catalogue of interesting objects; a view of the organization of timber and the configuration of salts when under the microscope. Thirty double copper plates of objects and apparatus. By George Adams, mathematical instrument maker to His Majesty, and optician to his royal highness the Prince of Wales. 4to, London, 1787.

Son of the preceding. Gives a very good account of the projection microscope, and like the other English writers, ascribes its invention to Lieberkühn. In the preface, p. x, he says: "When I first undertook the present essays I had confined myself to a re-publication of my father's work, entitled, Micrographia Illustrata" (see above). At the end of the preface is appended a list of 50 titles of authors consulted in the preparation of his essays. It is like a latter-day bibliography.

AMERICAN MICROSCOPICAL SOCIETY.

Proceedings and Transactions: 1878 to date. Published by the Secretary. As the secretary changes frequently there is no fixed place of publication.

AMERICAN MONTHLY MICROSCOPICAL JOURNAL, THE. Illustrated. Washington, D. C.: 1880—1902.

BAKER, HENRY.

Of Microscopes and the discoveries made thereby. Illustrated with many copper-plates. By Henry Baker, fellow of the Royal Society, and member of the Society of Antiquaries in London. In two volumes. Vol. I—The microscope made easy. Vol. II—Employment for the microscope.

Vol. I, A new edition, "Rerum Natura nusquam magis quàm in Minimis tota est." Plin. Nat. Hist. Lib. xic. 2. London, 1785.

According to the Index Catalog of the Library of the Surgeon General's Office, N. S., the first edition was produced in 1742, the second in 1743, and the "new edition" in 1785. The 1785 edition has been consulted in the preparation of this address. Baker's work was translated into French and into German, and it was well worthy of this distinction. It is probably the mistake of Baker in attributing the discovery of the projection microscope to Lieberkühn that gave the error such wide circulation through the translations of his work. The feeling of uncertainty concerning the history of the microscope in the mind of Baker may be inferred by this extract from his introduction: "Of Microscopes in General: To what accident, to what Country or to whom, we are obliged for the Invention of Microscopes, is not in me to determine." (Pp. 2-3.)

The dedication of this work, 1742, breathes so earnestly and with so much enthusiasm and good judgment the spirit of the true naturalist, that it is in large part here reproduced. The discovery of the importance of the bacteria and other micro-organisms since this dedication was written, now over 150 years ago, gives special point to what he says comparing the importance of the microscopic forms and those of large size—the "capitals" and the "little letters," as he calls them.

At a meeting of the Royal Society, October 28, 1742. Dedication: "To Martin Folkes, Esq., President, and to the Council and Fellows of the Royal Society of London. Gentlemen: An Attempt to excite in Mankind a general Desire of searching into the Wonders of NATURE, will, I persuade myself, be accepted favorably by you, whose Endeavours for the Advancement of Natural Knowledge, according to the Purpose of your Institution, are esteemed by all the World.

"It is something more than an hundred and twenty Years since the MICROSCOPE was happily invented; and to the valuable Discoveries made thereby, we stand indebted, as the following Sheets will shew, for a great Part of our present Philosophy. In such a Length of Time, it is however probable many more Advantages might have been reaped from it, had not some Difficulties and Discouragements prevented its general Use. . . .

"At the Beginning it was confined to very few; who, making a Secret of it, endeavoured all they could to keep it to themselves; and, when it became a little more publick, the Price was fixed so high, that the most Curious and Industrious, who have not always the greatest Share of

Money, could not conveniently get at it. Of late Years, indeed, the Expense has been much less; but then new Discouragements have started up from Mistake and Prejudice.

"For many have been frighted from the Use of it, by imagining it required great Skill in Optics, and Abundance of other Learning, to comprehend it to any purpose; whereas nothing is really needful but good Glasses, good Eyes, a little Practice, and a common Understanding, to distinguish what is seen; and a Love of Truth, to give a faithful Account thereof. Others have considered it as a mere Play-thing, a Matter of Amusement and Fancy only, that raises our Wonder for a Moment, but is of no farther Service; which Mistake they have fallen into, from being unacquainted with any Principles whereby to form a right Judgment of what they see. Many, again, have laid the Microscope aside, after a little Use, for want of knowing what Objects to examine, where to find, how to prepare, and in what Manner to apply them. The Trouble of managing it has also frighted some. . . .

"But we are now so fortunate as to have this Instrument greatly improved amongst ourselves, the Apparatus made much easier as well as more useful, and the Price considerably reduced. The Solar or *Camera Obscura* Microscope, and the Microscope for viewing Objects that have no Transparency, by throwing a strong reflected light upon them, are also new, Inventions, from whence great Things may be expected.

"Nothing therefore is now wanting, but a general Inclination to employ these Instruments, for a farther Discovery of the Minute Wonders of the Creation; which may not, perhaps, improve our Knowledge less than the grander Parts thereof. Bears, Tigers, Lions, Crocodiles, and Whales, Oaks, and Cedars, Seas and Mountains, Comets, Stars, Worlds and Suns, are the CAPITALS in Nature's mighty Volume and of them we should not be ignorant; but whoever would read there with Understanding, must make himself Master of the *little letters* likewise, which occur a thousand Times more frequently, and, if he does not know them, will stop him short at every Syllable. . . .

"The likeliest Method of discovering Truth is, by the Experiments of Many upon the same Subject; and the most probable Way of engaging People in such Experiments, is, by rendering them easy, intelligible, and pleasant. To effect this, is my Endeavour in the following Treatise."

BREWSTER, SIR DAVID.

A treatise on the microscope, forming the article under that head in the seventh edition of the Encyclopaedia Britannica, by Sir David Brewster, vice president of the royal society of Edinburgh, and corresponding member of the Institute of France. Edinburgh, 1837.

There is a very good account of the projection microscope with sunlight or oxyhydrogen light for illumination.

CARPENTER, WILLIAM B.

The Microscope and its revelations.

This is probably the greatest work on the microscope in the English language. Its various editions from the first, in 1856, to the last (8th, 1901), edited by the Rev. W. H. Dallinger, have been a storehouse of knowledge and the best that is known in the microscopical world. It does not deal to any great extent with the projection microscope, but is admirable in the history of the microscope itself.

CHEVALIER, CHARLES.

Des Microscopes et de leur usage. Description d'appareils et de procédés nouveaux, suivie d'expériences microscopiques puisées dans les meilleurs ouvrages anciens et les notes de M. Le Baillif, et d'un mémoire sur les diatomées etc. par M. de Brébisson. Paris, 1839. C. Chevalier was an "Ingénieur-Opticien, membre de la Société d'encouragement pour l'industrie nationale; l'un des lauréats (médaille d'or) à l'exposition de 1834, etc."

There is a good discussion of the history of the microscope in this work. Chevalier follows the English in ascribing the discovery of the projection miscroscope to Lieberkühn. Chevalier's figure of the projection microscope (fig. 18 of the text, above) indicates how advanced were the instruments constructed by him.

COLE, AARON HODGMAN.

Manual of biological projection and anesthesia of animals. Pp. 200, Chicago, Ill., (1907). Illustrated.

This work is founded on the series of articles on the subject originally published in the Journal of Applied Microscopy, and contains many good hints.

DECHALES.

(R. P. Claudii Francisci Milliet Dechales Camberiensis e' Societate Jesu.) Cursus, seu Mundus Mathematicus. Tomus Tertius. Complectens Architecturam Militarem, Hydrostaticam, Tractatus de Fontibus & Fluviis, de Machinis Hydraulicis, & de Navigatione, Opticam Perspectivam, Catoptricam, & Dioptricam. Editio altera ex Manuscriptis Authoris aucta & emendata, operâ & studio R. P. Amati Varcin ejusdem Societatis. Annison che fiorisce. Lugduni, Apud Anissonios, Joan. Posuel & Claud. Rigaud. M. DC. LXXXX. Cum Privilegio Regis.

The part relating to the projection microscope is contained in: "Tractatus XXIII. Dioptrica, seu de Radio Refracto." Liber I, Propositio LVII. Theorema (p. 680). "Exigui prototypi, unieâ lente convexâ amplificatam imaginem, in pariete exhibere." Also, Liber II, Propositio XX, Problema (p. 696). "De nocte exigui prototypi ingentem in muro imaginem distinctam exhibere daubus lentibus." See the figure (fig. 7) and quotation above, p. 14. There are four folio volumes of this work. Each volume contains many figures. The first edition appeared in 1674.

GAGE, SIMON HENRY.

The Microscope. An introduction to microscopic methods and to histology. Tenth ed., 1908. First edition, 1881. Ithaca, New York.

GORING, C. R., AND PRITCHARD, ANDREW.

Micrographia, containing practical essays on reflecting, solar, oxy-hydrogen gas microscopes; micrometers, eye-pieces, &c, &c. London, 1837.

This is one of the most satisfactory of the older works, and deals in a modern fashion with the subjects named in the title page. On pp. 170, 171, Pritchard gives a very detailed account of the early use of the oxy-hydrogen light for use with a lantern by Birkbeck in lectures at the London Mechanics' Institute, 1824.

HARTING, PIETER.

Das Mikroskop, Theorie, Gebrauch, Geschichte und gegenwärtiger Zustand derselben, von P. Harting, Professor in Utrecht. Deutsche Originalausgabe vom Verfasser revidirt und vervollständigt. Herausgebeben von Dr. Fr. Wilh. Theile, grossherzoglich Sächsischem Medicinalrathe, in drei Bänden. Zweite wesentlich verbesserte und vermehrte Auflage. Mit 466 in den Text eingedruckten Holzstichen und einer Tafel in Farbendruck. Braunschweig, 1866.

First German edition, 1858. Original Holland edition: Het mikroskoop, deszelfs gebruik, geschiedenis en tegenwoordigen toestand. Een handboek voor natur—en genees-kunde. Utrecht, 1848, 1849. Gr. 8°, 3 din, met 5 pl.

Dr. Harting (born 1812, died 1885) was for many years professor in Utrecht university, teaching, among other things, the microscopic structure of plants and animals, etc. In his later years he went over to zoology and comparative anatomy. He was a good type of the scholarly men Holland has been producing for so many generations. This book on the microscope is one of the best that has ever been produced, and one refers to it over and over again with renewed pleasure. In discussing the controverted points of history in the development of the microscope his step is almost always sure in the slippery maze of conflicting testimony. His research in this field was profound and his judgment sound. Considering the statements of Poggendorff and a study of original sources leads me to think that Dr. Harting was mistaken in ascribing the invention of the projection microscope to Kircher. (See above, in the address, and Harting, Bd. III, p. 279 *et seq.*)

JOURNAL OF APPLIED MICROSCOPY AND LABORATORY METHODS. Rochester, N. Y., 1898—1903.

This contains a series of articles by A. H. Cole on projection.

JOURNAL OF THE ROYAL MICROSCOPICAL SOCIETY. Illustrated. London, 1878 to date.

Bibliography of works and papers relating to the microscope, microscopical methods, and histology. It also includes a summary of many of the papers.

KIRCHER, ATHANASIUS.

(Athanasii Kircheri Fuldensis Buchonii è Soc. Jesu Presbyteri). Ars Magna Lucis et Umbrae. In X. Libros digesta. Quibus Admirandae Lucis & Umbrae in mundo, atque adeò universa natura, vires effectusque uti nova, ita varia novorum reconditiorumque speciminum exhibitione, ad varios mortalium usus, panduntur. Editio altera priori multò auctior. Sicuti tenebrae ejus ita & lumen ejus, Psal, 138. Amstelodami, Apud Joannem Janssonium à Waesberge, & Haeredes Elizaei, Weyerstraet. Anno cIↃ IↃↃ LxxI, (1671) Cum Privilegio Sacr. Caesar. Majestatis, & Ord. Holl & Westfr.

The first edition of this work was published in 1646. According to Poggendorff, p. 436: "Kircher spricht von der Laterna magica in seiner *Ars magna lucis et umbrae,* aber nicht in der ersten Auflage von 1646, sondern in der spätern von 1671." In the edition of 1671, the projection microscope is considered in Liber x, p. 768, Problema IV (see pl. II, III, below). Also in Cryptologia Nova, pars prima; De Projectione Figurarum inquamlibet distantiam per Solem, p. 792 (see pl. I).

This is a wonderful folio volume of over 800 pages, ranging in interest from the "experimentum mirabile, de imaginatione Gallinae," p. 112, where, to illustrate the point, is a hypnotized chicken on a chalk line, to the burning of the investing Roman fleet at Syracuse by Archimedes with a "Speculum causticum," with, on p. 764, a picture of the scene; and finally to the height of all knowledge in the last chapter, p. 795, "Epilogus sive Metaphysica Lucis et Umbrae." No part of knowledge, real or imaginary, was neglected by the old encyclopedists.

LEISS, C.

Die optischen Instrumente der Firma R- Fuess, deren Beschriebung, Justierung und Anwendung; Mit 233 Holzschnitten im Text und 3 Lichtdrucktafeln. Leipzig, 1899.

This work deals fully with optical projection, including micro-projection. All sources of illumination are discussed and a very excellent account is given of the different forms of heliostat.

MAYALL, JOHN, JR.

Cantor Lectures on the [History of the] Microscope delivered before the Society for the Encouragement of Arts, Manufactures and Commerce, Nov., Dec., 1885. London, 1886. This monograph of 97 pages is a model of clearness, accuracy, and fairness. It is abundantly illustrated. On p. 42 he ascribes the invention of the projection microscope to Lieberkühn. This is difficult to understand, as the author is so accurate in most matters. He gives two figures of the solar microscopes of Adams and Cuff, 1744-1746, but does not deal adequately with the projection microscope.

PETRI, R. J.

Das Mikroshop von seinen Anfängen bis zur jetzigen Vervollkommnung für all Freunde dieses Instruments, von. Regierungsrath Dr. med. R. J.

Petri, ordentl. Mitglied des kaiserlichen Gesundheitsamtes und Vorstand des bakteriologischen Laboratoriums daselbst. Mit 191 Abbildungen im Text und 2 Facsimiledrucken. Berlin, 1896.

"Niemals zurück" is the proverb on the title page. While the projection microscope is not dealt with in this book the development of the microscope is well done in text and figures. At the end there is a bibliography of 73 different works or editions, beginning with the Opticæ thesaurus Alhazeni (1535, 1572, Latin translations), and ending with the work of Dr. Henri van Heurck, 1891.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON. Illustrated. London, 1665 to date.

POGGENDORFF, J. C.

Geschichte der Physik Vorlesungen gehalten an der Universität zu Berlin. Mit vierzig holzschnitten. Leipzig, 1879.

On the title page is also this motto: "Ex umbra in solem." The history given by Poggendorff is divided into three periods: (1) The ancient or Greek period extending to the fall of Alexandria (460 A. D.); (2) The Arabic and Middle Ages (460 to the end of the 16th century, including therefore Kopernicus and Keppler); (3) The period of Galileo and Newton, 17th and part of 18th centuries—about 150 years.

PORTA, GIOVANNI BATTISTA DELLA.

Magiae Naturalis, sive de miraculis rerum naturalium. First edition 1553-4; 2d, 35 years later, 1589.

Natural Magick by John Baptista Porta, a Neapolitane. In twenty books:

1. Of the Causes of Wonderful things.
2. Of the Generation of Animals.
3. Of the Production of new Plants.
4. Of Increasing Household-Stuff.
5. Of changing Metals.
6. Of counterfeiting Gold.
7. Of the Wonders of the Load-stone.
8. Of strange Cures.
9. Of Beautifying Women.
10. Of Distillation.
11. Of Perfuming.
12. Of Artificial Fires.
13. Of Tempering Steel.
14. Of Cookery.
15. Of Fishing, Fowling, Hunting, &c.
16. Of Invisible Writing.
17. Of Strange Glasses.
18. Of Statick Experiments.
19. Of Pneumatick Experiments.
20. Of the Chaos.

Wherein are set forth all the Riches and Delights of the Natural Sciences. London. Printed for Thomas Young, and Samuel Speed; and are to be sold at the three Pigeons, and at the Angel in St. Paul's Church-yard. 1658.

This English edition is from the second Latin edition of 1588-9. One can but admire the zeal and industry shown by the old writers who were

"learned in all the knowledge of their time." A couple of paragraphs from the preface will give the point of view more clearly than anything else. The capitalization and punctuation of the original is preserved so that the reader may compare the appearance of a printed page in 1658 with one at the present day:

"If this Work made by me in my Youth, when I was hardly fifteen years old, was ſo generally received and with ſo great applauſe, that it was forthwith tranſlated into many Languages, as Italian, French, Spaniſh, Arabick; and paſſed through the hands of incomparable men: I hope that now coming forth from me that am fifty years old, it ſhall be more dearly entertained. For when I ſaw the firſt fruits of my Labours received with ſo great Alacrity of mind, I was moved by theſe good Omens; And therefore have adventured to ſend it once more forth, but with an Equipage more Rich and Noble.

"From the firſt time it appeared, it is now thirty-five years, And (without any derogation from my Modeſty be it ſpoken), if ever any man labored earneſtly to diſcloſe the ſecrets of Nature, it was I: For with all my Minde and Power, I have turned over the Monuments of our Anceſtors, and if they writ anything that was ſecret and concealed, that I enrolled in my Catalogue of Rarities. Moreover, as I travelled through France, Italy, and Spain, I conſulted with all Libraries, Learned men, and Artificers, that if they knew anything that was curious, I might underſtand ſuch Truths as they had proved by there long experience. Thoſe places and men, I had not the happineſs to ſee, I writ letters too frequently, earneſtly desiring them to furniſh me with thoſe Secrets, which they eſteemed Rare; not failing with my Entreaties, Gifts, Commutations, Art, and Induſtry. So that whatſoever was Notable, and to be deſired through the whole World, for Curioſities and Excellent Things, I have abundantly found out, and therewith Beautified and Augmented theſe, my Endeavours, in NATURAL MAGICK, wherefore by moſt earneſt Study, and conſtant Experience, I did both night and day endeavour to know whether what I heard or read, was true or falſe, that I might leave nothing unaſſayed: for I oft thought of that Sentence of Cicero, It is fit that they who deſire for the good of mankinde, to commit to memory things moſt profitable, well weighed and approved, ſhould make tryal of all things. To do this I have ſpared no Pain nor Coſt, but have expended my narrow Fortunes in a large magnificence. . . . .

"If I have over-paſſed ſome Things or not ſpoken ſo properly of them as I might; I know there is nothing ſo Beautiful, but it may be Adorned; Nor ſo full, but it may be Augmented. J. B. P."

WHITE, ANDREW DICKSON.

A history of the Warfare of Science with Theology in Christendom. Two vols. New York, 1896.

One cannot read Dr. White's book without a profound conviction of the truth of the quotations placed at the beginning: "Thoughts that great hearts once broke for, we breathe cheaply in the common air."—Lowell. "Discipu-

lus est prioris posterior dies."—Publius Syrus. "Truth is the daughter of time."—Bacon. "The Truth shall make you free."—St. John, VIII, 32.

WOODWARD, JOSEPH JANVIER.

On Photo-micrography with the highest powers. Amer. Jour. Sci. and Arts, 1866.

Report on Photographing histological preparations by Sunlight. 1871.

Magnesium, Oxy-calcium and electric lights applied to photography. 1870.

Application of Photography to micrometry. Phila. Med. Times, 1876.

Dr. Woodward, Med. Department, U. S. Army, produced some of the best photo-micrographs which have ever been made. He says, in the report on photographing by sunlight, p. 8: "And rejecting all eye-pieces and amplifiers I have aimed to obtain a magnification of not less than 1,000 diameters by distance alone." He commends very highly the electric light.

WRIGHT, LEWIS.

Optical projection, a treatise on the use of the lantern in exhibition and scientific demonstration with 232 illustrations. London, 1891.

This work covers the whole field of projection with the magic lantern, including the projection microscope. The work is by one who had much experience, and who gave in this book the benefit of that experience. If one has not a personal instructor this book will be found almost equal to one.

ZAHN, JOANNES.

Oculus artificialis teledioptricus sive telescopium, ex abditis rerum naturalium et artificialium principiis protractum nova methodo, eaque solida explicatum a comprimis e triplici fundamento physico seu naturali, mathematico dioptrico et mechanico, seu practico stabilitum. Folio, 770 pages, Plates and tables. Herbipoli, 1685-6. Same, second edition, 797 pages, plates and tables. Norimbergae, 1702.

Both these editions are in the Library of the Surgeon General's office at Washington. Zahn, p. 225, says: "Cum in Lucerna megalographica veri microscopii speciem habeamus." . . . On comparing the two editions this expression was found in both. Zahn gives several figures of the magic lantern which look strikingly like some of the simplest forms of the present day. Compare also plate Va.

ZEISS, CARL.

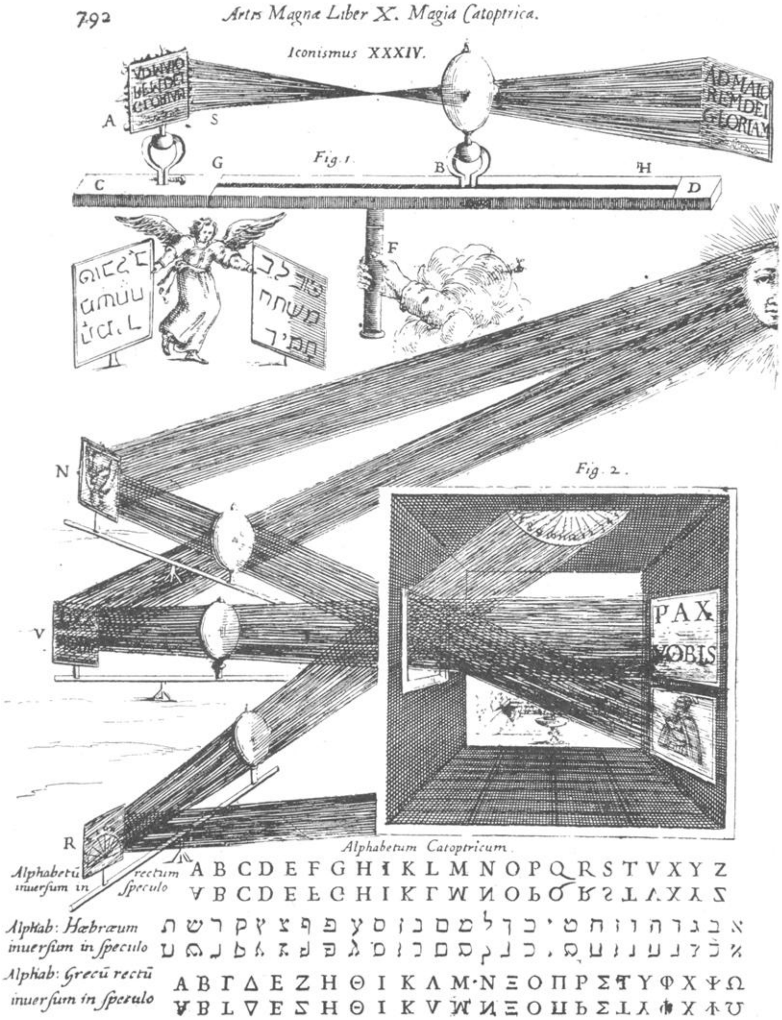
Catalogs for the last 25 years.

If one would see in the most striking way the development of the microscope and its accessories he must compare the successive editions of a great optical manufacturing house. That of Zeiss has been selected, for it, by universal consent, would be considered the greatest in our times.

ZEITSCHRIFT FÜR WISSENSCHAFTLICHE MIKROSKOPIE UND FÜR MIKROSKOPISCHE TECHNIK. Illustrated. Braunschweig, 1884 to date.

Methods, bibliography and original papers.

PLATE I



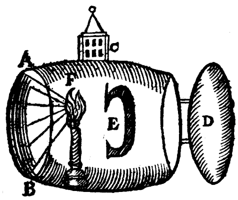
792
Artis Magnæ Liber X. Magia Catoptrica.
Iconismus XXXIV.
AD MAIO REM DEI GLORIAM
A
S
G
Fig. 1.
B
H
C
D
F
N
Fig. 2.
PAX VOBIS
V
R
Alphabetum Catoptricum.
Alphabetū rectum inuersum in speculo
A B C D E F G H I K L M N O P Q R S T V X Y Z
Alphab: Hæbræum inuersum in speculo
Alphab: Grecū rectū inuersum in speculo
Α Β Γ Δ Ε Ζ Η Θ Ι Κ Λ Μ Ν Ξ Ο Π Ρ Σ Τ Υ Φ Χ Ψ Ω

PLATE II

Problema III.

Lucernam artificiosam construere, quæ in remota distantia scripta legenda exhibeat.

Fiat lucerna, ea, qua hic factum esse vides figura cylindracea; in cujus basi AB speculum concavum, quod parabolam quantum fieri potest, affectet, erigatur.

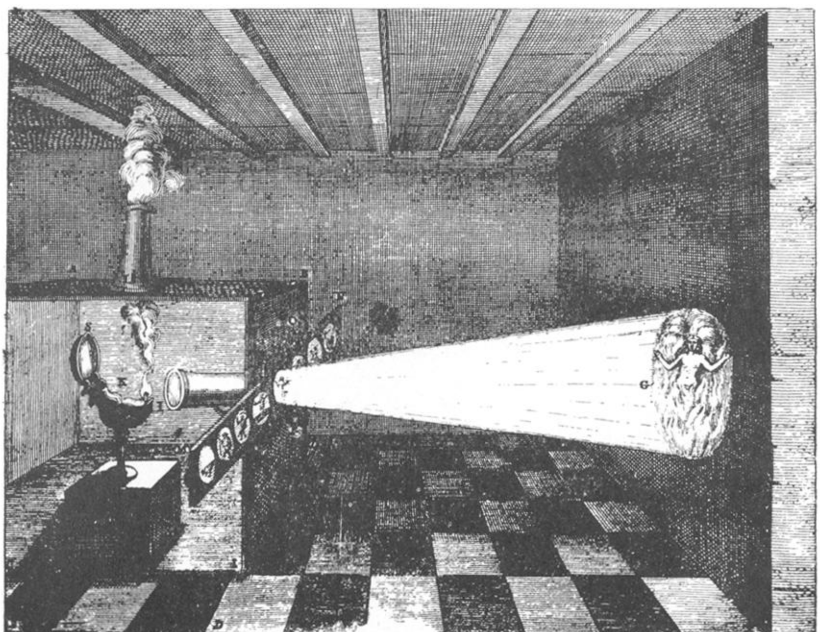


Lucerna Catoptrica. Intra hujus speculi focum applicetur F flamma candelæ, habebisque quæsitum. Nam tam inusitato splendore fulgebit, ut noctu etiam minutissimas literas ope telescopii inspectas nullo negotio exhibeat. Remotè verò flammam intuentes, ingentem ignem esse existimabunt; augebunt lumen, si latera cylindri interiora ex fulgido stanno in ellipsin elaborata fuerint. Sed inventum figura apposita satis declarabit. E manubrium, D fenestram, C infumibulum designat.

Problema IV.

De Lucerna Magicæ seu Thaumaturgæ constructione.

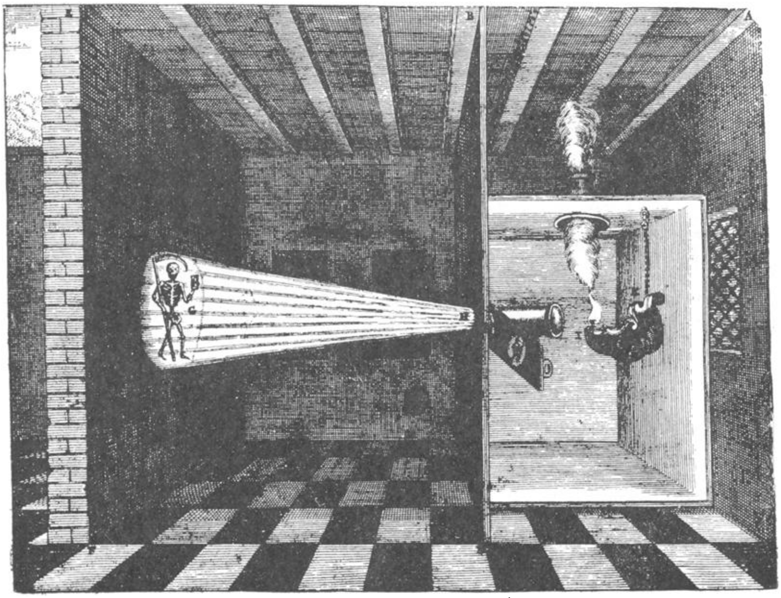
Quamvis in arte Magna Lucis & umbræ folio 767. hujusmodi Lucernæ mentionem fecerimus & fol. 793. modum per solem simulacrorum in obscurum locum transmittendorum, una cum coloribus ad ea depingenda requisitis tradiderimus: Quia tamen in citatis locis, inventionem hanc prorsus singularem ab aliis majoribus inventionibus adornandam reliquimus, accidit, ut multi rei novitate



allecti ad eam excolendam animum adjecerint, Quos inter primus fuit Thomas Walgenstenius Danus, haud infimæ notæ Mathematicus, qui recolens meas in describendis iis inventiones Lucernam fol. 767. a nobis descriptam, in meliorem formam reduxit, quàm & postea magno suo lucro diversis in Italia principibus vendidit,

dudit, ut proinde jam Romæ res pœne vulgaris fit. Non est autem alia inter illam & a nobis descriptam Lucernam differentia, quàm quod complurium imaginum species in obscuro cubiculo dictus Walgenstenius ostendat satis nitidè & politè, nec non cum summa spectantium admiratione. Nos in Collegio nostro in obscuro cubiculo, 4. novissima summo intuentium stupore exhibere solemus. Est autem res visu dignissima, cum ejus ope, vel integras scenas satyricas, Tragicas theatrales & similia ordine ad vivum exhibere liceat.

Artificium verò Catoptricum, quod nos fol. 793. Artis Magnæ Lucis & umbræ docuimus, non differt ab hac nova Lucerna, nisi quod illa per mobilem Lucernam, nos radiis solis in speculum, in quo simulacra rerum descripta sunt, reflectentibus in immobili interioris alicujus domus aut cubiculi pariete, coloribus ad vivum exhibemus omnia ea, quæ per Lucernam mobilem monstrari solent; quamvis etiam eodem in loco modum sine solis radiis, per speculum concavum aut lentem diaphanam res repræsentandi doceamus. Quæ omnia hic fusius prosecutus sum, ut Lectori, unde hæc nova arcana Lucernæ (quàm non immeritò Magicam & Thaumaturgam, à mirifica rerum quarumcunque tandem in obscurato cubiculo aut intempestæ noctis silentio repræsentatione appellandam duximus) originem suam traxerint. Quibus præmissis nil jam restat, nisi ut fabricam ejus paucis exponamus.



Fiat ex ligno receptaculum A. B. C. D. deinde in L caminus, ut Lucerna per illum fumum suum emittere possit, Lucerna verò K in medio ponatur vel affixa filo ferreo vel supra fulcrum M è regione foraminis H, intra quod tubus palmaris committatur, in tubi verò principio I lenticulare vitrum melioris notæ inseratur in foramine verò, seu in fine tubi H vitrum planum probè elaboratum ponatur, in quo coloribus aqueis & diaphanis quidquid volueris pingatur; hoc pacto intra cubiculum VTSX in muro candido lumen lucernæ vitrum lenticulare transiens imaginem in H vitro plano depictam (quæ inverso situ in vitro ponitur) rectam & in muro grandiorem exhibebit, omnibus coloribus ad vivum expressam. Nota tamen

EXPLANATION OF PLATES

Plate I

Reproduction of a part of Kircher, p. 792, showing the use of sunlight for illumination, and that the objects to be shown in the darkened room (camera obscura) were painted on plane metallic mirrors (*N*, *V*, *R*). Below are Roman, Hebrew, and Greek letters showing the usual appearance and also the mirror image which must be painted on the mirrors in order that the image on the screen will appear in the normal form after passing the lenses. In fig. 1 at the top of the cut is a kind of optical bench showing the metallic mirror (*A*) with letters in reverse upon it but erect in the screen image at the right. The projection lens is shown at *B*.

Plate II

Projection apparatus shown by Kircher, p. 768. The radiant is a lamp (*K*) with a concave mirror or speculum (*S*) for concentrating the light upon the object. The lamp is in a dark box. The objects are on a long glass slide as in the present day toy lanterns. The image at *G* illustrates one of the amusements of the period.

Plate III

Magic lantern shown by Kircher, p. 769. The apparatus in this case is separated by a partition from the room in which are the screen and the spectators.

Plate IV

A. Projection or solar microscope (Adams Essays, 1771, plate 6, figs. 4, 5, 6, 7, 8). Fig. 4 shows the movable mirror (*K-L*) placed outside the shutter in the sun; *O-P*, screws in the square plate to fasten the instrument in the shutter; *M-N*, thumb screws by which the mirror is turned to hold the sun's rays in the right direction. The large tube, *A-C-D*, contains the condenser and receives the shorter tube, fig. 5. Fig. 5 shows the tube into which the objectives are fixed. If for large objects the lens (fig. 6) is screwed into the end, *g*, for smaller objects, the objectives are arranged in a piece (fig. 8) sliding into the opening at *q*. Notches along the objective slider indicate when the lens is centered. The specimen to be examined is inserted at *h*. For high powers the substage condenser shown at fig. 7 is put in the tube between *d-h*. At *b* is a rack and pinion for focusing the object.

B. Thompson automatic 90-degree arc lamp with Prof. Wm. A. Anthony's parallel movement, arc-striking device. *M*, electromagnet; *A. M*, arc-striking mechanism consisting of an armature of soft iron, and parallel links or hinges allowing the upper carbon to extend to the right and downward when the current is off. This brings the carbons in contact. When the current is on the electromagnet pulls up the armature, thus lifting the upper carbon vertically and to the left. The arrows indicate the direction of the current.

Plate V

A. Shows the arrangement of parts for projection with a photographic objective of 105 mm. focus. No tube is used and objects up to 60 mm. in diameter can be projected.

B. Shows the projection microscope in position for high powers. The tube of the microscope is large (50 mm.) and short (9 to 10 centimeters), so that the field may not be restricted. *Al*, automatic arc lamp with Anthony's arc-striking device; *Cw*, condenser and water-bath; *Sw*, stage and stage water-bath; *Ob*, *Sc*, objectives on a triple nose piece with a 25-centimeter screen just behind them; *Lb*, lathe bed on which the different parts move independently.

Plate Va

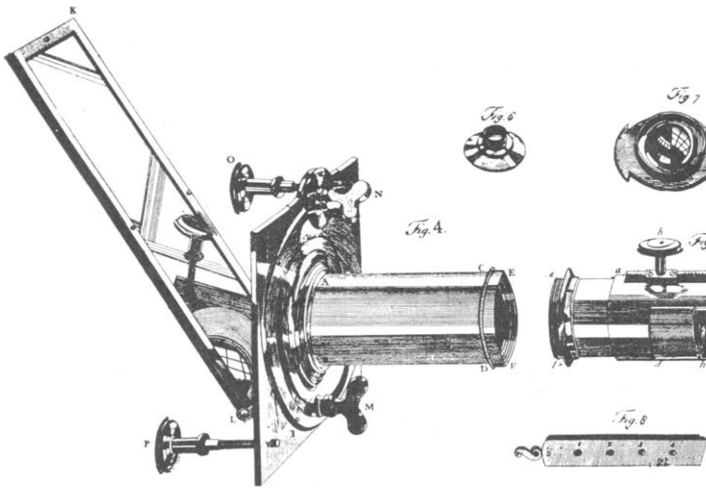
From Zahn's Oculus Artificialis, 1685 and 1702, showing the use of an *Amplifier*.

Fig. 2. Projection with a double convex lens (C-D), and divergence of the rays, thus giving a large image, by means of a plano-concave lens or amplifier.

This is the earliest illustration I have found showing the use of an amplifier in projection. (See p. 37 and figs. 13, 17 and 18 in the text.)

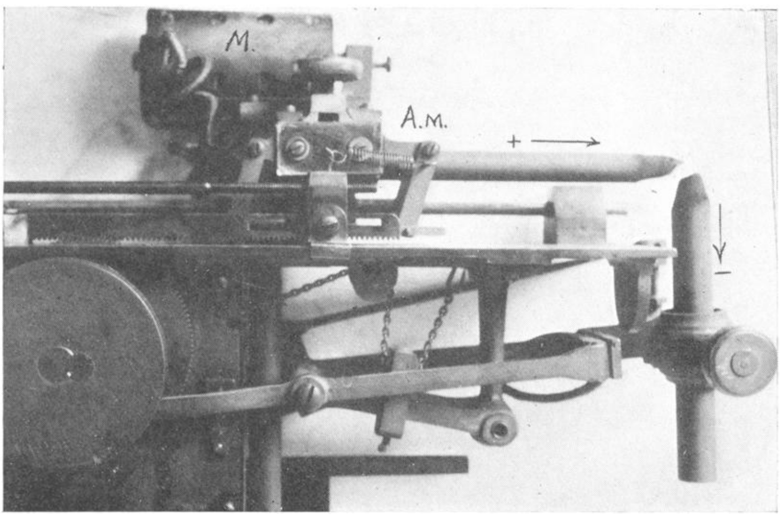
Fig. 3. Projection by means of two convex lenses. The first, (C-D), gives a real, inverted image at O-K; the second, (E-F), projects this real image and re-inverts it, thus giving a final erect image (G-H). Compare the modern projection microscope when an ocular is used (fig. 14 in the text).

PLATE IV.



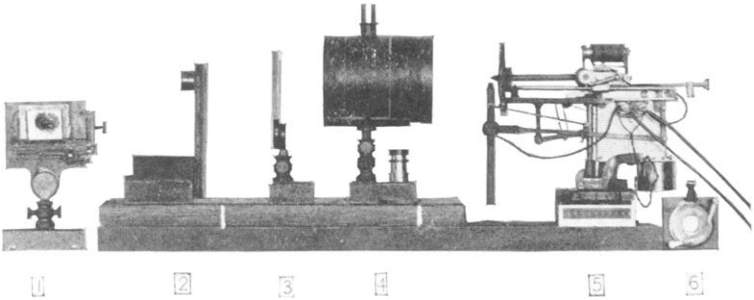
London Printed for & Publish'd by Geo: Adams No. 60 Fleet Street May 20th 1787.

A.

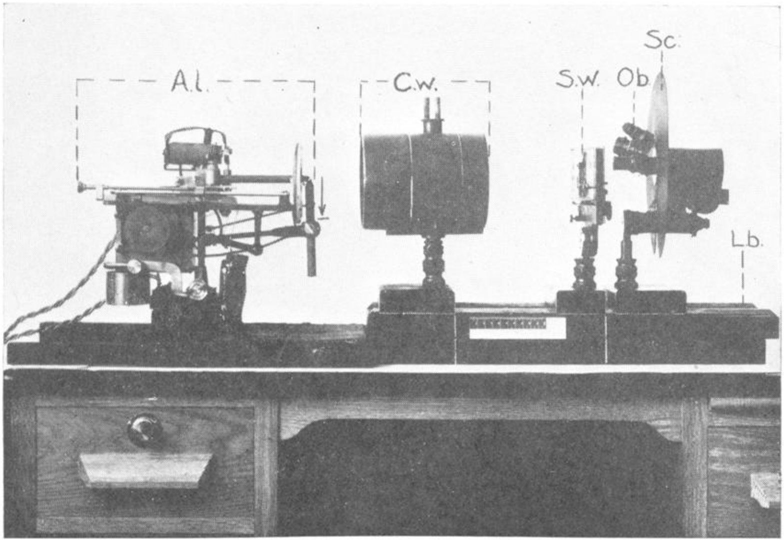


B.

PLATE V.



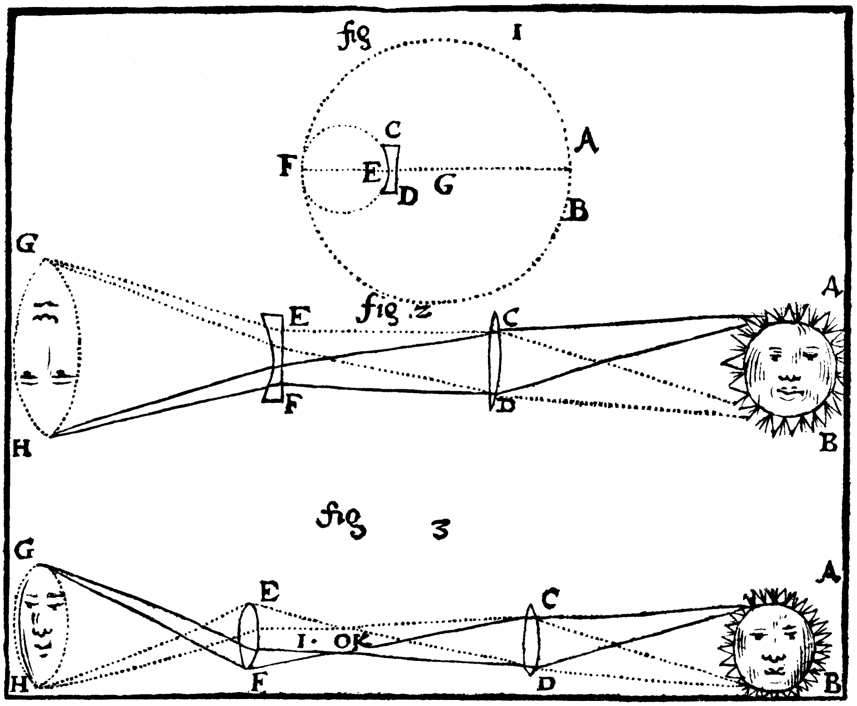
A.



B.

PLATE Va.

Tubum ex meris Lentibus convexis apparatum, possuntque oculares Lentes esse duæ vel una tantùm habebitque se ordinatio Tubi hujus per modum Telescopii Astronomici, quod alias oculo applicatum objecta exhibet eversa, hic autem debitè aptatum Solem ostendet erectum.



Cum primo modo immissio instituitur, debet Tubus communis sive Telescopium Hollandicum paulò magis produci, quàm opus esset ad ordinariè objecta sivè debet Lens cava paulò amplius à Lente convexâ